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December 31, 2003

ASTWG Technology and Standards Research

Final Letter Report

Prepared for

Department of the Air Force
45th Space Wing (AFSPC)
Safety Office - 45 SW/SE
Patrick AFB, FL 32925

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Final Letter Report

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14. ABSTRACT
This letter report is the first deliverable under Task 103 (Subtask 002) of the basic contract (F086050-02-C-0018) between SRS Technologies, Inc. and Research Triangle Institute's (RTI's) Center for Aerospace Technology/Launch Systems Safety Department (CAST/LSSD). This document summarizes RTI's research efforts in the areas of advanced propellant servicing technologies, dynamic planning/scheduling systems technologies and a benchmarking of activities in the national/international space industry standards development.

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Abstract

This letter report is the first deliverable under Task 103 (Subtask 002) of the basic contract (F086050-02-C-0018) between SRS Technologies, Inc. and Research Triangle Institute's (RTI's) Center for Aerospace Technology/Launch Systems Safety Department (CAST/LSSD). This document summarizes RTI's research efforts in the areas of advanced propellant servicing technologies, dynamic planning/scheduling systems technologies and a benchmarking of activities in the national/international space industry standards development.

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1 Introduction

This letter report is the first deliverable under Task 103-subtask 2 of the basic contract (F086050-02-C-0018) between SRS Technologies, Inc. and Research Triangle Institute's (RTI's) Center for Aerospace Technology/Launch Systems Safety Department (CAST/LSSD). This document summarizes RTI's research efforts in the areas of advanced propellant servicing technologies, dynamic planning/scheduling systems technologies and a benchmarking of activities in the national/international space industry standards development.

1.1 Background

NASA/Kennedy Space Center is leading a national effort to identify advanced spaceport technologies needed to meet the vision for access to space. The Advanced Spaceport Technology Working Group (ASTWG) is comprised of a diverse group of stakeholders throughout the aerospace, technical and scientific communities. During 2003, ASTWG held one national conference, two technology team mini-retreats and several subworking group meetings to brainstorm the operational capabilities envisioned for spaceports in the near term (2005-2009), mid-term (2010-2015) and far-term (2016-2028).

In order to achieve the operational capabilities identified in these meeting, a technology investment strategy needs to be developed. The ASTWG Technology Team analyzed the capability "roadmaps" and identified five common technology "themes" that cut across all of the roadmaps. These themes, highlighted below and defined in the ASTWG Baseline Study, were termed Technology Focus Areas (TFAs):

1. Advanced Servicing Technologies
2. Command, Control and Monitoring
3. Inspection and System Verification
4. Transportation, Handling and Assembly
5. Planning, Documentation, Analysis and Learning (PDAL)

Figure 1 is the high-level technology area roadmap outlined in the ASTWG Baseline Study. Due to their similarities in technology research areas, TFAs 2 and 5 were combined in this high–level roadmap and renamed the Spaceport Control Information Infrastructure area.

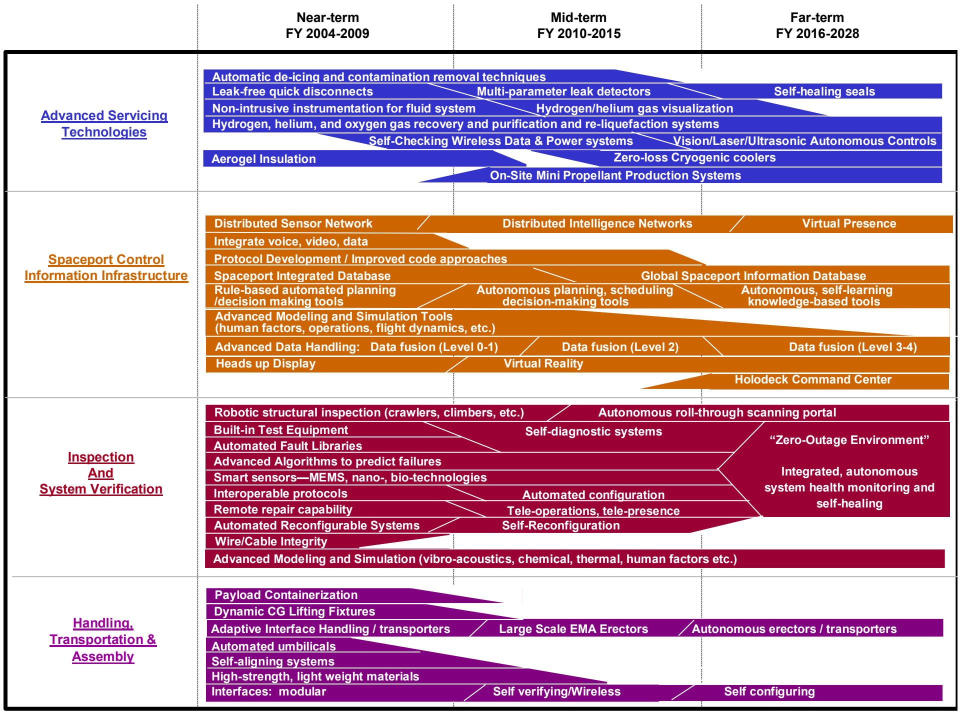


Figure 1 Technology Area Roadmap

1.2 Scope

RTI was tasked with researching two critical technology areas: propellant servicing as it relates to the Advanced Servicing TFA (see Figure 2), and dynamic planning/scheduling as it relates to the PDAL TFA (see Figure 3). The propellant servicing research focused on personnel protection equipment and transportation/storage/transfer/disposal associated with various propellants. Dynamic planning/scheduling research focused on the data collection, data mining, decision-making/schedule generation and reporting elements. These research efforts targeted both aerospace and non-aerospace industry best practices and technology development.

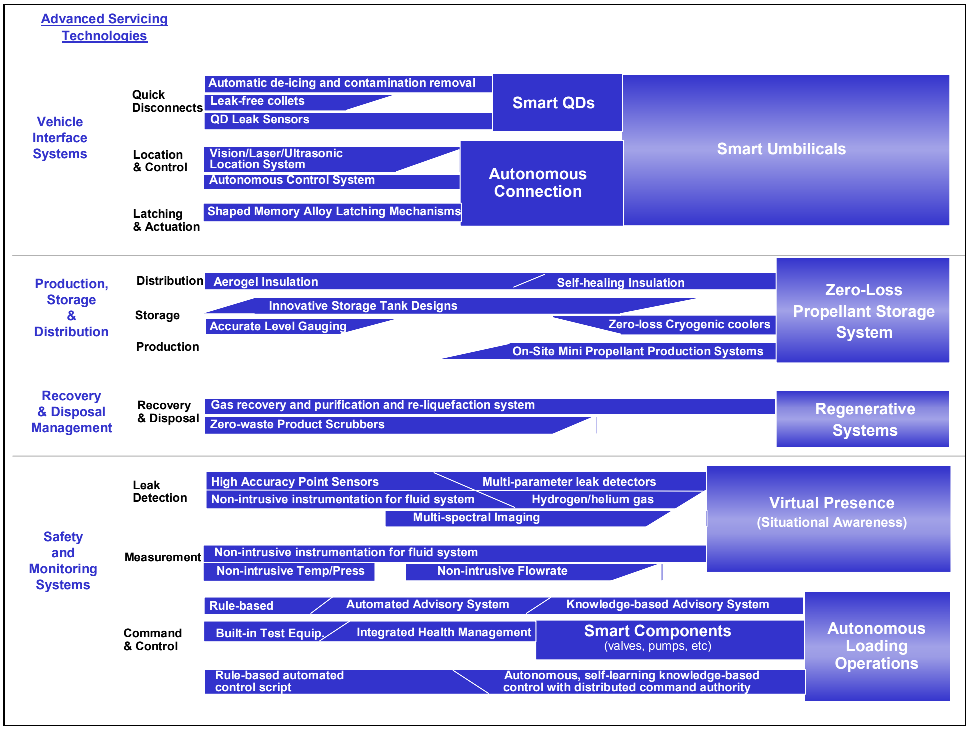


Figure 2 Advanced Servicing Technology Focus Area Roadmap

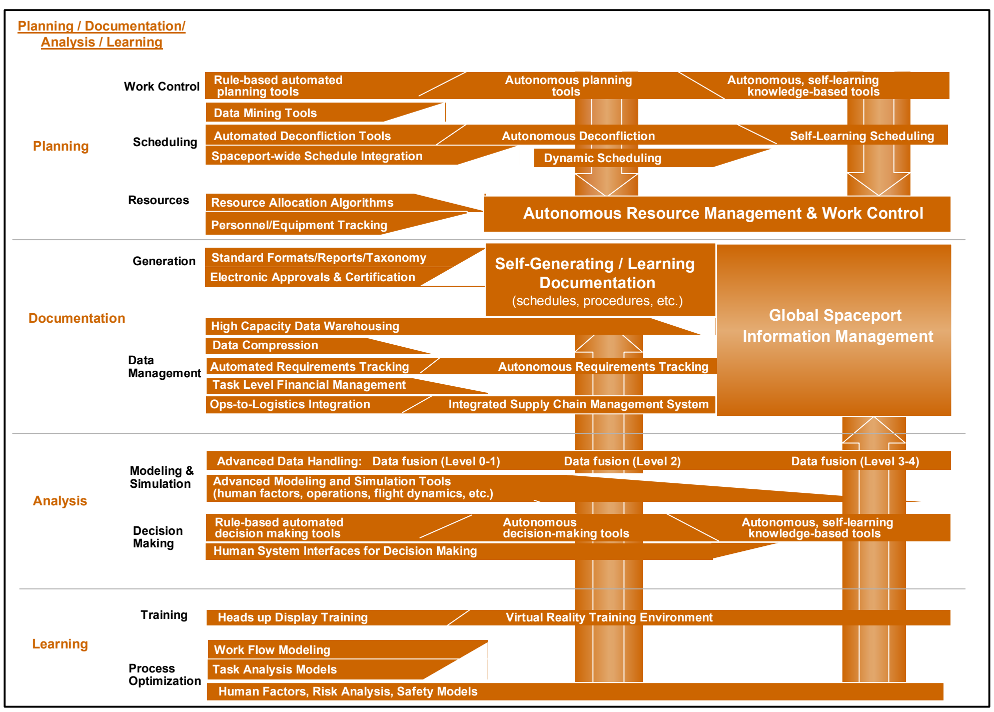


Figure 3 PDAL Technology Focus Area Roadmap

2 Advanced Servicing

This section documents RTI's research and analysis of the Advanced Servicing TFA, and includes the results from a technology area benchmarking effort, RTI's findings and recommendations, and a list of what RTI deems to be the critical technologies for this TFA. These critical technologies are then mapped to the ASTWG high level TFA roadmap depicted in Figure 2.

2.1 Hypergolic Propellants Servicing Technology Area

Hypergolic propellants are fuels and oxidizers that ignite on contact with each other and need no ignition source. This easy start and restart capability makes them attractive for both manned and unmanned spacecraft maneuvering systems. Although they do not have the extreme temperature requirements of cryogenics, most hypergols are highly toxic and reactive, which makes them costly to transport, store, transfer, and dispose. Examples of hypergols considered in this effort include

- Hydrazine (HZ, N_2H_4)
- Monomethyl Hydrazine (MMH, CH_3NHNH_2)
- Unsymmetrical Dimethylhydrazine (UDMH, 1,1-dimethylhydrazine)
- Nitrogen Tetroxide (NTO, N_2O_4).

2.1.1 Benchmarking

In an effort to identify novel technologies and processes that would facilitate the future spaceport Advanced Servicing operational concept, a benchmarking effort was performed. This effort baselined the procedures and systems used in aerospace and non-aerospace industries in which the functional requirements are similar to that envisioned for a future spaceport.

This benchmarking effort baselined the processes and technologies used by:

- NASA and its contractors (e.g., United Paradyne Corp, CalTech)
- DoD (primarily the Air Force, but also the Army and Navy)
- Commercial aerospace companies (e.g., Boeing, LMCO, Hamilton Sundstrand, Aerojet, Arch Chemical)
- Non-aerospace users (e.g., power plants, foam manufacturers, chemical producers).

Findings reported here are based on a literature review and interviews conducted with a broad range of hypergol users, manufacturers, researchers, shippers, and industry analysts. Appendix A - Research Notes contains the raw data generated by RTI on this topic.

Note that solutions-grade hypergols used in non-aerospace applications are not combustible and are classified differently from the 99% pure propellant-grade hypergols. As a result, the benchmarking of practices in non-aerospace applications for potential transfer to the launch industry is limited. The following paragraphs highlight some of the current industry practices in hypergol operations.

2.1.1.1 Transportation

For hypergol transportation, KSC-developed standards for tanker trucks have been adopted by the DOT and are used by the DoD, Arch Chemicals, and other organizations. The DoD and NASA use standard 30- or 55-gallon drums or similar assets. Vandenberg Air Force Base (VAFB) uses rail tank cars for delivery. All propellant-grade hypergol transportation today is by ground — aircraft transport is not yet allowed.

2.1.1.2 Storage

KSC currently uses tanker trucks or 4BW cylinders for hypergol storage, but is moving to develop bulk on-site storage. DoD weapons are stored "wet" (fueled and ready to deploy) for decades. The DoD was reported to have some bulk storage at the Titan (Cape Canaveral) launch pad facility as well as at bulk on-site storage at VAFB. Since the Aerojet bulk storage facility in California was mothballed, Arch Chemical was reported to have the sole commercial bulk storage facility near Mobile, Alabama. Other hypergolic propellant users store via the same standard drums or facilities used by DoD or NASA.

2.1.1.3 Transfer

The DoD performs some loading operations with no servicing cart where pumping is direct from the storage drum into the fuel tank, with the head being supplied by low-pressure nitrogen. LMCO was reported to have implemented an automated remote loading system at VAFB, although their attempts to automate a leading cart were not viable due to variations in receiving tanks. However, LMCO has successfully eliminated its intermediate servicing cart tank. NASA was generally reported to load hypergols via manual servicing carts. Some transfer operators run process water continuously to allow spills to be quickly rinsed.

2.1.1.4 Personnel Protective Equipment

NASA personnel and contractors generally follow NASA safety procedures developed for the unique application for a man-rated system using large quantities of hypergols. These procedures require that SCAPE suits and dosimeter badges be used for all operations. For lower quantities of hypergols, the DoD typically does not employ dosimeter badges and instead uses a cartridge type respirator, face shield, and gloves. VAFB uses SCAPE suits where large quantities of hypergols are loaded. LMCO was reported to use lower-cost disposable or Class B chemical suits when suits are necessary. When pumping hydrazines or performing other operations involving open hydrazines, operators wear respirators, face shields, gloves, and rubber smocks.

In hypergol storage facilities, plant air is constantly monitored. When hydrazines are under significant pressure, users typically seal the area, turn on safety lights, and restrict personnel access. One entity reported using dosimeter badges—which may not be specific to hydrazines—issued on a periodic (quarterly) basis; KSC uses dosimeter badges for all operations. Dams and drains ensure any spill is captured in the hazardous waste sump.

2.1.1.5 Disposal

KSC currently has limited on-site waste disposal via a UV Rayox system and wastewater treatment. Surprisingly large amounts of hydrazine waste can benefit the anaerobic sewerage process and may be safely disposed into the sewer system. Otherwise, hypergol waste (solvent and water based) is trucked away by contractor to an off-site commercial incinerator. KSC can recycle some hypergol waste through the manufacturer but only when it is mixed with water. Other users, including DoD and commercial operators, have similar waste dispose practices to those of KSC. A test stand operator reported using afterburners installed in exhaust system for tests to ensure no hazardous waste entered the outside environment.

2.1.2 Findings and Recommendations

Given the toxicity of today's hypergolic propellants, many organizations currently have research programs to develop less toxic or nontoxic replacements for these propellants. Success in one of these programs would provide breakthrough improvements in spaceport operations; however, this effort focused on how a spaceport could most efficiently and safely handle even the "ugly" propellants.

Findings and recommendations by technology area are given in the following sections.

2.1.2.1 Transportation

Transportation of hypergolic propellants was reported to be mature with relatively few opportunities for optimization. However, air transportation of hypergols would improve schedule efficiencies, but is currently not allowed.

Develop procedures and PPE to enable air transportation for hypergols.

2.1.2.2 Storage

VAFB employs bulk on-site storage.; however, no other spaceports researched have made this investment. On-site storage would support a higher launch rate as well as provide for contingency operations. Most hypergol users reported using an inert gas blanket on the liquid to extend and improve shelf life.

Implement bulk on-site hypergol storage for increased flight rate and contingency operations.

2.1.2.3 Transfer

Opportunities for reducing the cost of hypergol operations were identified in automation, remote operations, and servicing cart elimination/simplification. Prior attempts to fully automate servicing carts have failed due to the variations of payloads and vehicles. Boeing and LMCO were reported to have eliminated the servicing cart intermediate tank, which eliminates one transfer. Some hypergol users reported transferring without a servicing cart, saving the cost of cleaning and maintaining the servicing cart. Furthermore, development of standard prefilled tank modules that could be changed rather than pumping hypergols could reduce costs.

Eliminate or simplify hypergol-servicing cart. Automate (including developing enabling standards) or use remote transfer operations to remove operator from vicinity of toxins. Develop standard prefilled tank module to eliminate liquid transfer in uncontrolled outdoor environment

2.1.2.4 Personnel Protection Equipment (PPE)

Most hypergol facilities employ site monitors that were reported to provide adequate protection. Outside of NASA, dosimeter badges and worker testing are performed on a periodic basis (e.g., quarterly) to determine if existing procedures are working. Portable hypergol sniffers are used occasionally. Users did identify a need for enhanced sensing technology in the form of on-chip nanosensors that provide fast response time, have high accuracy and sensitivity (ppb level), and are rugged.

Costs might also be reduced by use of SCAPE suits only when making or breaking connections. Also, the use of disposable Class B chemical suits or other alternatives appropriate to the level of possible exposure could benefit spaceport operations.

Work with other working groups/industries to optimize PPE. Develop on-chip nanosensors. Limit use of SCAPE suits to making or breaking hypergol connections.

2.1.2.5 Disposal

Disposal of hypergols is generally performed by hazardous waste contractors who haul the waste away to a processing plant where it is presumably incinerated. Users typically pay a fee based on pH or similar measure. Some users, including KSC, reported that some hydrazines are beneficial to the anaerobic sewerage process, and a surprisingly large amount of that material can be disposed of in the normal wastewater treatment system. KSC also has a contract that allows aqueous hydrazine waste to be recycled back into the propellant process. Greater use of water as a cleaning solvent (rather than alcohol) was identified as a possible means to reduce hazardous waste cost. In addition, optimization of decontamination systems (e.g., ion exchange resins) may decrease disposal concerns.

Use water as cleaning solvent rather than alcohol. Certify waste for disposal into sewer system. Adopt efficient decontamination systems (e.g., ion exchange resins).

2.1.3 Critical Technologies

Listed below are technologies that emerged as critical to achieving the ASTWG Advanced Servicing operational concept for hypergolic propellant servicing:

Table 1 Critical Technology –Hypergols

H1	• Enhanced hypergolic sensing technologies:
	- On-chip nanosensors
	- Distributed sensor networks
	- Standard wireless encrypted data links from vehicle to ground hypergol systems
	- Noninvasive sensing of temperature, pressure, flow rate, and other factors to enable feedback on operations without introducing the possibility of leaks
	- Improved response time, accuracy, sensitivity, and maintainability
	- Centralized monitoring systems for leak or concentration detection
H2	• Optimization of hypergolic fueling carts:
	- Elimination of intermediate fueling tank
	- Automation through development of standards for interfaces
H3	• Improved hypergolic storage technology:
	- Development of pre-filled hypergol tanks to enable modular replacement
	- Automated and/or remote loading operations to eliminate fueling carts
	- Simplified low cost manufacturing for on-site, on-demand production of hypergols
H4	• Optimized hypergolic propellant handling plans, procedures, engineering controls, and PPE:
	- Protective clothing comfortable for outdoor use in accordance with levels of potential exposure
	- Emergency showers, breathing apparatus, and other PPE ready for immediate standby use in hypergolic fueling areas
	- Integral ground systems for containing and mitigating spills
	- Leak-proof quick connect fittings with redundant seal paths
	- Machine vision for automated alignment and mating of umbilical
	- Smart umbilicals that provide automatic process verification for issues such as connection, continuity, flow rate, and leak tightness that are capable of taking corrective action if acceptable conditions are not met

	- Integral static electricity grounding systems
H5	• Optimized hypergolic system cleaning and decontamination (e.g., ion exchange resins) such that most waste can be accepted by on-site sewage system or recycled back into process
H6	• Hypergolic storage containers with:
	- Integrated temperature control
	- Integral pumping and shield gas systems
H7	• Standardization of on-board hypergolic tanks such that operations are common, routine, and repeatable

2.2 Cryogenic Propellant Servicing Technology Area

In gaseous form, oxygen and hydrogen have such low densities that extremely large tanks would be required to store them aboard a rocket. But cooling and compressing them into liquids vastly increases their density, making it possible to store them in large quantities in smaller tanks. The tendency of cryogenics to return to gaseous form unless kept super cool makes them difficult to store over long periods of time. They are thus less satisfactory as propellants for military rockets, which must be kept launch-ready for months at a time. The high efficiency of the liquid hydrogen/liquid oxygen combination, though, is worthwhile when reaction time and storability are not too critical. Examples of cryogenic fluids considered in this effort include

- Liquid Oxygen (LOX) – remains liquid at -298° F (-183° C)
- Liquid Hydrogen (LH2) – remains liquid at -423° F (-253° C), reported to be the most expensive and largest volume commodity for launch operations
- Liquid Nitrogen (LN2) – similar to LOX in that it remains liquid at -321° F (-196° C)
- Liquid Helium (LHe) – similar to LH2 in that it remains liquid at -425° F (-268° C).

2.2.1 Benchmarking

In an effort to identify novel technologies and processes that would facilitate the future spaceport Advanced Servicing operational concept, a benchmarking effort was performed. This effort baselined the procedures and systems used in aerospace and non-aerospace industries in which the functional requirements are similar to that envisioned for a future spaceport.

This benchmarking effort baselined the processes and technologies used by

- Propellant applications (e.g., NASA, Boeing, LMCO, DoD)
- Process applications (e.g., electronics and petrochemical industry)
- Hydrogen-based energy (e.g., future automotive fuel cell applications).

Findings reported here are based on a literature review and interviews conducted with a broad range of cryogenic users, manufacturers, shippers, and industry analysts. Appendix A - Research Notes contains the raw data from RTI research of this topic.

Note that because hydrogen is the most expensive and largest volume propellant commodity in launch operations, most of the research in this section focused on hydrogen. The following paragraphs highlight some of the current industry best practices in cryogenic operations.

2.2.1.1 Transportation

The DOT has established regulations for cryogenic fluid transportation such that all applications are essentially handled the same except for possibly some military customers. For propellant applications, delivery is generally via a 13,000-gallon tanker truck from the New Orleans area. NASA requires capacity for 30 tankers/day and has tried rail service but found it was too slow. KSC has contracts directly with cryogenic vendors and consolidates the supply contracts for all of the NASA field centers. The DoD obtains its propellants from the DESC, which negotiates contracts with commercial vendors. Commercial launch vehicle companies purchase their cryogenic propellants either from DESC or directly from vendors. The commercial launcher companies independently contract for a supply of 3-5 trailers per day, which enables a lower price than NASA due to the more economic logistics pattern.

Cryogenic propellant purity is less than that required by other applications, but because the products are all produced in the same process, propellant users get the same product required by, for example, the electronics industry. The DoD and NASA order their cryogenic materials to MIL specifications, but NASA is slowly moving to lower cost CGA (commercial) specifications.

Industry experts indicated that for future energy applications, hydrogen would be provided by tanker truck or, more likely, by reforming natural gas at or near the fueling station. Energy companies (e.g., Exxon Mobil, Shell, BP) plan to take over commodity business.

2.2.1.2 Storage

For cryogenic propellant storage, NASA uses four 1960s-era, 800,000-gallon dewar spheres kept filled at all times (due to age), requiring a 30 tanker/day surge in delivery after a launch. The VAFB launch rate is lower than that of KSC/CCAFS; therefore, VAFB's cryogenic propellant tanks are generally not kept filled at all times.

Liquid hydrogen requires special attention to insulation due to the fact it is 120° F colder than liquid oxygen. Across aerospace and non-aerospace applications, some hydrogen storage tanks are super insulated (Mylar and aluminum foil with hard vacuum), whereas others are lower-cost soft vacuum and perlite insulated. In partnership with others, including Air Products, LMCO developed densified cryogenic loading technology as part of X-33, but it is not yet used in operations.

KSC is considering an on-site production system similar to the existing GN2 pipeline. Note that 95% of the hydrogen market today is for gaseous hydrogen, some of which is piped from the gas supplier plant into petroleum refiners' facilities in California, Texas, and Louisiana—a set up similar to KSC's nitrogen pipeline.

The storage infrastructure for a hydrogen energy carrier economy is now being designed. Vehicles will use high-pressure gas, metal hydride, or cryogenic storage; however, it appears that high-pressure (~10 ksi) gaseous hydrogen will be the fuel of choice for a vast majority of applications. Building codes for structures that may encounter hydrogen are now being developed. These applications are leveraging sensing technologies originally developed for NASA launch operations. Gas sensors are favored over flame detectors due to the false alarm rate.

2.2.1.3 Transfer

At KSC, a team of safety people and a fire truck monitor cryogenic propellant transfers from tanker truck to storage tank. Outside of launch operations, the truck driver alone does the transfer of cryogenic fluids from the truck to a storage tank. Special purging and connection processes developed over 50 years are now standard across aerospace and non-aerospace applications. When transferring large quantities of cryogenic propellants, handlers wear Nomex suits. Pumping is via electrical pump or gas pressure.

Transfer from KSC's spherical storage tanks to vehicle is via a precooled, long, 1960s-era, vacuum-jacketed pipe that introduces significant losses. Hence, KSC is considering liquefaction at the launch pad. There are no common interfaces or requirements existing in the launch industry today that might enable the ASTWG operational concept of "plug and play".

Standard, safe fueling nozzles that are similar in operation to gasoline dispensers are now being designed for the future hydrogen energy consumers. A technical hurdle exists in the heat of compression of gaseous hydrogen, which prevents a 100% fill. This hurdle is being addressed through wireless temperature feedback from the vehicle tank to the filling pump system. Additionally, adequate grounding is imperative for safe hypergolic fuel transfer, and may be ensured through more conductive tire material, and/or operations that require users to ground themselves prior to a transfer.

2.2.1.4 Disposal

Because hydrogen and oxygen are natural atmospheric constituents, the direct venting of boil off is not an environmental hazard. KSC's spherical storage tanks boil off at a rate of 600 gallons/day per sphere. This boil off is burned via a flare stack if operations are occurring in the area to prevent any fire hazards. KSC is considering powering a fuel cell with the waste or reliquifying.

2.2.2 Findings and Recommendations

Overall, industry experts observed that the cryogenic system infrastructure used by KSC for Shuttle operations was developed and installed in the 1960s. These legacy systems were not designed for Shuttle operations and are therefore inherently suboptimal. These systems also suffer from decades of wear and the fact that new materials and better cryogenic systems have been developed in subsequent years for other applications. A complete redesign of the KSC cryogenics systems would be required to optimize Shuttle operations. Nonetheless, KSC's expertise in cryogenic propellant operations should be leveraged to benefit other spaceport operators.

Findings and recommendations by technology area are given in the following sections..

2.2.2.1 Transportation

Current modes of transportation — tanker truck, dewar, vacuum jacketed pipe — were reported to be generally mature with well-established DOT standards and few opportunities for optimization of operations. Commercial specifications for propellants, CGA in particular, were identified as lower cost than the MIL specifications currently used by most launch operators. Current users of the Florida spaceport reported independent arrangements for cryogenic propellant such that consolidation might enable cost reductions and perhaps even on-site production. Because liquid hydrogen suffers particularly high losses in vacuum jacketed pipe transfers, liquefaction of gaseous propellants at the launch pad should be considered as a future operational improvement.

> Evaluate liquefaction of gaseous propellants at the launch site.
>
> Use commercial (CGA) specifications rather than more costly MIL specifications.
>
> Optimize cryogenic delivery rate per the launch rate.
>
> Evaluate cost reduction opportunity for consolidation of propellant supply for all spaceport customers.
>
> Consider on-site production.

2.2.2.2 Storage

Cryogenic storage systems, including super insulated hard vacuum and soft vacuum tank designs were reported to be mature. In the emerging hydrogen energy carrier economy, gaseous hydrogen was reported to be of most market interest and storage system development. Building codes for structures that would include hydrogen are now in development. Gas sensors and flame detectors originally developed for space launch applications are being further developed for commercial fueling stations. Lower-cost and more robust gas sensors are now needed for this market as well as for space launch applications.

> Participate in the development of building codes and sensor networks for structures storing hydrogen.

2.2.2.3 Transfer

Special purging and connection processes for cryogenic propellants have been developed and optimized over the past 50 years such that they are standard across all industries. KSC was reported to monitor tanker truck to spherical storage tank transfers with a fire truck, whereas truck drivers alone performed transfers for other clients. The FAA Commercial Space Transportation Advisory Committee (COMSTAC) Launch Operations and Support Working Group was reported to be developing standards for vehicle cryogenic propellant interfaces. The vast majority of industrial hydrogen applications, as well as the emerging hydrogen energy carrier economy, primarily transfer gaseous hydrogen by pipeline similar to the KSC nitrogen pipeline.

Optimize tanker truck to storage tank transfers to commercial best practices. Develop common interface requirements and procedures with similar working groups to enable the ASTWG vision of "plug and play".

2.2.2.4 Disposal

Boil off can be vented to the atmosphere, burned via flare stack, reliquified, or used in another process or system such as a fuel cell. The economics of these alternatives should be evaluated.

Evaluate options for optimal use of boil off

2.2.3 Critical Technologies

Listed below are technologies that emerged as critical to achieving the Advanced Servicing operational concept for cryogenics:

Table 2 Critical Technologies-Cryogenics

C1	• Enhanced sensing technologies:
	- Low-cost reversible gas sensors with fast response time in broad temperature and concentration range (leak detection, explosive limit, and process level detection) that are not poisoned by other gas species
	- Multiplexed sensors (one controller handle five or more sensors) and distributed sensor networks
	- Reduced false alarm rate flame detectors
	- Integrated flame detectors and flame imaging systems
	- Standard wireless encrypted data links from vehicle to ground systems
	- Noninvasive sensing of temperature, pressure, flow rate, and other factors to enable feedback on operations without introducing the possibility of leaks
C2	• Umbilical technology:
	- Leak-proof quick connect fittings
	- Machine vision for automated alignment and mating of umbilicals
	- Smart umbilicals that provide automatic process verification for issues such as connection, continuity, flow rate, and leak tightness that are capable of taking corrective action if acceptable conditions are not met
	- Replacing pyro-operated disconnects with electromechanical devices
	- Integral static electricity grounding systems
C3	• Cryogenic loading pumps with improved seals, magnetic coupling, and/or the magneto-caloric effect

C4	• High strength, low cost hydrogen embrittlement resistant alloys for structural applications
C5	• Low-cost modular process for on-site cryogenic production and/or gas liquefaction at the departure point with the ability to quickly ramp up or down output in response to dynamic flight rates
C6	• Spaceport propellant gas pipeline distribution system similar to the KSC nitrogen pipeline
C7	• Technologies for low cost liquefaction of boil off (no loss cryogenic storage tank) or the use of boil off for another process
C8	• Breakthrough in super insulated pipes that would allow efficient cryogenic transfers over long distances (e.g aerogel, multi-layered insulation (MLI), layered composite insulation (LCI), polyimides, and composites) • The performance of MLI is known to be sensitive to localized compression effects and trapped residual gases produced by the combined mechanical influences of bending and spacers. Bending-type mechanical effects come from four sources: bending, as in handling and installation; thermal contraction and expansion; line pressure reaction forces; and the weight of the line (sagging). Spacers are employed in the design of vacuum-jacketed lines to keep the inner line concentric within the outer line during manufacturing and to counteract these mechanical effects during operation. Spacers are made from low-thermal-conductivity materials to minimize heat conduction. • The following characteristics are some key advantages of the aerogel beads: free flowing, fill small cavities, minimal dusting, nonsettling, do not compact, no preconditioning needed, and can be molded or formed using binders. carbon black opacifier improved the performance of the aerogel beads
C9	• Cryogenic densification for future launch vehicles

2.3 Solid Propellant Servicing Technology Area

Research in the solid propellant field is focused mostly on refining the application (improving efficiency, etc.), rather than improving operations (e.g., ancillary technology improvements). A primary thrust in handling is developing "insensitive munitions," wherein solid propellants (munitions) are essentially nonreactive until user initiated. As with other hazardous propellant chemicals, environmental impacts are also an issue. Although there are numerous research experts at universities and within NASA/DoD, very few people handle solid propellants in significant quantities outside of the primary launch contractors and operators. Examples of solid propellant elements identified in this effort include

- Aluminum
- Ammonium nitrate, Ammonium perchlorate (AP)
- Boron
- Lithium
- Magnesium
- Nitrocellulose, Nitroglycerine
- Perfluoro-type
- Potassium perchlorate.

2.3.1 Benchmarking

In an effort to identify novel technologies and processes that would facilitate the future spaceport Advanced Servicing operational concept, a benchmarking effort was performed. This effort baselined the procedures and systems used in aerospace and non-aerospace industries in which the functional requirements are similar to that envisioned for a future spaceport.

This benchmarking effort baselined the processes and technologies used by

- NASA and its on-site contractors
- DoD (Air Force, Army, and Navy)
- Commercial aerospace companies (e.g., Boeing, LMCO)
- Non-aerospace users (e.g., Western Electrochemical, Alcoa).

Findings reported here are based on a literature review and interviews conducted with a range of users, manufacturers, researchers, shippers, and industry analysts. Appendix A - Research Notes contains the raw data from RTI research of this topic. Few groups handle solid propellants in the form that a spaceport would handle. Similar industries include fireworks, munitions, and solid propellant raw material (e.g., aluminum, ammonium perchlorate industries. For the purpose of this study, benchmarking primarily focused on those with direct solid propellant experience. The following paragraphs highlight some of the current industry practices in solid propellant operations.

2.3.1.1 Transportation

Solid propellants are cast into the motor in the factory, unlike liquid fuel rockets that can be fuelled at the launch pad. This means they have to either be: 1) limited in size to be transportable (as for the Delta and Ariane strap-on motors); 2) cast in segments, with the segments assembled at the launch base (as for Titan and the Space Shuttle); or 3) cast in a factory near the launch site (actually done for large test motors intended for Saturn V upgrades). It is expected that scenarios 1 or 2 are applicable to future spaceports and are the only scenarios considered for this analysis.

Solid propellants transportation is dependent on the size of the propulsion unit. For spaceport applications (e.g., solid rocket boosters, SRBs), common flat bed trailers (e.g., a heavy- duty rail car with a specially built cover) can be used to transport propellants. NASA's SRBs are broken down into four segments for easier transport. Munitions with solid propellants and other aerospace solid rockets (e.g., Delta II solid rocket booster) for the Department of Defense are transported similarly (via train/truck). Grounding solid rocket boosters in transit to prevent electrostatic discharge is a primary concern.

2.3.1.2 Storage

Many solid propellants are classified by DoD as nondetonable propellants – severe explosions of these propellants are not feasible. If a solid rocket motor in storage were (accidentally) ignited while the motor was mounted on fixtures that block the motor exhaust, an internal pressure-caused explosion could occur. This type of pressure rupture would produce low overpressures that might result in some limited facility venting. Fragments generated by such an event would be retained inside facilities that have explosion proofing.

With regard to NASA's handling of explosive materials like solid propellants, the following handling measures are cited for storage:

- Facilities having fire walls, fire protection systems, operational shields, substantial dividing walls, blast resistant roofs, containment structures, and earth covered magazines
- Electrostatic discharge controls such as conductive floor tile and legstats or conductive work shoes
- Lightning protection with resistance of 25 ohms or less to ground; metallic surfaces containing explosives must be bonded and grounded
- Building, magazines, and containers must have the appropriate safety markings
- Solid propellants are not to be stored with initiating explosives, detonators, explosive devices with detonators, or ammunition

2.3.1.3 Transfer

The primary handling concerns for solid propellants are mechanical (lifting rockets, transferring from rail cars to transporters upon delivery from manufacturer, etc.) and electrical. The main concern is electrostatic discharge. Solid propellants in a composite case act essentially like a large capacitor. Grounding the unit to ensure a level voltage potential is the major technology need.

With regard to other technology issues related to solid propellants, existing technologies are satisfactory and advanced technologies are not likely to play a major role in future spaceport handling of solid propellants/rockets. Temperature and shock/vibration are monitored for solid rockets before use. Data is continuously charted and analyzed to determine if a solid rocket has experienced any traumatic conditions that could create problems. Some launch facilities require radiographic inspection of solid rockets upon receipt from the manufacturer, but that practice is not currently mandatory or used widely.

2.3.1.4 Personnel Protective Equipment

Solid propellant handlers often wear legstats or wriststats for operations around fuelled spacecraft, propellants, or solid motors. Beyond electrostatic discharge considerations, personal handling of solid rockets (propellants) at final stages (i.e., at a spaceport) does not require extraordinary precautions. Simple protective clothing (gloves, coveralls, etc.) may be used by technicians or handlers for solid rockets.

2.3.1.5 Disposal

Because solid propellants are typically delivered to spaceports with propulsion units, ready to fly, there should be no excess propellant of which to dispose. However, NASA does reuse the solid rocket housing, by recovering the spent casing and cleaning out propulsion by products and remaining propellants. The Solid Rocket Booster (SRB) recovery operation at KSC's Hangar AF renovates the SRBs from space shuttle launches and prepares them for reuse. Cleaning of the SRB tubes generates two waste streams on a "per launch" cycle basis. The first waste stream of 60,000 gallons (total flow) is generated by pressure washing of the SRB tube. This waste stream is discharged to the Air Force Main Sewage Treatment Plant via a sewer main. The second waste stream is generated by a hydrolasing process to remove ablative material from the SRB tube. The waste stream is filtered and aerated prior to disposal. This second waste stream is discharged to Class G-II groundwater via an 83,000 square foot grassed sprayfield (wetted surface area) at the rate of 13,500 gallons per day (average daily flow) and not to exceed 20,000 gallons per day (maximum).

2.3.2 Findings and Recommendations

The advantages of the solid rocket boosters include easy handling. Once the propellant is manufactured and shipped, the technicians need no extensive protective clothing or procedures. The solid rocket fuel can be stored indefinitely in its solid state with only random inspections to insure that its seals are still functioning. In a solid rocket motor there are no moving parts that can fail just by mechanical movement.

Although much of the technological advancement in the field of solid propellants will be made in refinements of the propellants themselves, limited opportunities do exist for some improvements in handling technologies. For example, handling issues for solid propellants can be improved by developing improved shock absorbing transportation technologies that can further reduce the likelihood for damage to the critical grain structure of the solid propellant.

Findings and recommendations by technology area are given in the following sections..

2.3.2.1 Transportation

In future spaceport scenarios, solid propellants are delivered by the manufacturer in "ready to fly" rockets (i.e., negligible or minimal assembly on-site) that can be transported by rail or truck to the spaceport. Technologies for accomplishing this are already in place, but could be refined. Primary technologies in this area are related to sensors for monitoring propellant environment in transit.

Refine solid rocket sensors (temperature, vibration) for in-transit monitoring

2.3.2.2 Storage

Most solid propellants used in spaceport applications follows industry standards for explosion-proof facilities and electrostatic discharge prevention. Automated monitoring of temperature, vibration, and voltage is a logical extension of these measures.

Maintain controlled and monitored environments in storage facilities

2.3.2.3 Transfer

Transfer issues related to solid propellants/rockets are primarily in regard to moving rocket assemblies. Some solid rockets are assembled from several segments at the launch facility, whereas others are delivered by the manufacturer in single units. Comprehensive handling procedures are typically employed to ensure the proper lifting (e.g., crane attachment, load positioning) and movement procedures to prevent/minimize unwanted shock or vibration. Additional shock absorption or monitoring technologies might be employed in the future.

Maintain clear procedures for moving rocket assemblies and minimize/eliminate mechanical shock or vibration

2.3.2.4 Disposal

When cleaning storage facilities or refurbishing spent propulsion casings, alternative, environmentally friendly cleaning solvents and materials fare required for the disposal/clean-up process.

Develop more environmentally friendly cleaning solvents

2.3.3 Critical Technologies

Listed below are technologies that emerged as critical to achieving the Advanced Servicing operational concept for solid propellant servicing:

Table 3 Critical Technologies – Solid Propellants

S1	• Vibration

	– Wireless, noncontact vibration monitoring systems
S2	• Temperature
	– Wireless, noncontact temperature monitoring systems
S3	• Cranes
	– Precision cranes with advanced vibration monitoring/control
S4	• Insensitive munitions (propellants)
	– Reduced reactivity with external hazards (e.g., static charge, mechanical shocks)
	– E.g., Paraffin-based solid fuel to replace existing technology
S5	• Alternative, environmentally-friendly cleaning solvents and materials
	– Replace CFC-113 and methyl chloroform cleaners with low vapor pressure cleaners

2.4 Petroleum/Hydrocarbon Propellant Servicing Technology Area

Petroleum (hydrocarbon) fuels are among the most common fuels used in industry. Unlike the more sophisticated solid, cryogenic, and hypergol propellants, petroleum-based fuels are a fairly stable technology area. Storage, metering, and monitoring typically use established, well-known technologies, although fully automated systems are an area of development. Otherwise, progress here tends to be incremental improvements and like most of propellants and fuels, environmental impact is a primary concern. Most of the research in fuel handling equipment is distributed throughout companies in this field.

Much of the technology for handling petroleum fuels is decades old. The most common flow rate meters, positive displacement meters, are based on technology that is 60 to 70 years old. Companies today are still trying to maximize the capability, efficiency, and reliability of these meters. Newer technologies such as coriolis meters and sonic meters are based on technology that might only be 20 to 30 years old. Other petroleum handling technologies, such as filtration, are also deemed acceptable and are not receiving a great deal of research and development when compared to technology for more high tech systems like fuel cells and hydrogen. Examples of petroleum fluids considered in this effort include

- Refined kerosene (e.g., RP-1)
- Jet fuel (e.g., JP-8)
- Propane
- Ethylene oxide.

2.4.1 Benchmarking

In an effort to identify novel technologies and processes that would facilitate the future spaceport Advanced Servicing operational concept, a benchmarking effort was performed. This effort baselined the procedures and systems used in aerospace and nonaerospace industries in which the functional requirements are similar to that envisioned for a future spaceport.

This benchmarking effort baselined the processes and technologies used by

- NASA and on-site contractors
- DoD
- Commercial (e.g., Boeing, LMCO)
- Manufacturers.

Findings reported here are based on a literature review and interviews conducted with a range of users, manufacturers, shippers, and industry analysts. Appendix A - Research Notes contains the raw data from RTI research of this topic. There is a tremendously broad range of users that can serve baseline analysis – from automotive fuel pump equipment to refinery handling procedures. The following paragraphs highlight some of the current industry best practices in petroleum/hydrocarbon propellant operations from across industry.

2.4.1.1 Transportation

With regard to liquid propellants, NASA's bulk handling measures generally apply to quantities greater than single minimum size shipping containers such as one 55-gallon drum or one 500-pound (net weight) cylinder. For NASA KSC, RP-1 (kerosene rocket propellant) is transported by 7,000-gallon capacity tankers (similar to a gasoline tanker) from the source to end-use facility at NASA.

The tanker is designed to transport hydrocarbon fuel and has a capacity of 7200 gallons with an 800-gallon ullage in JP-8 (jet fuel) service and 7000 gallons with a 1000-gallon ullage in RP-1 service. Hydrocarbon fuels are normally offloaded by external pumping units.

The tanker consists of a horizontal tank mounted on a dual wheel, tandem-axle chassis assembly. The tanker is a pump load/offload configuration capable of flow rates up to 400 GPM. The tanker has a single DOT 3AA2400 GN2 cylinder that pneumatically controls the tanker vent, bottom fill/drain valve, and brake interlock system. Included in the design are a liquid level indicator and a high-level control mechanism that prevents overfilling. During offloading, a low-level sensor communicates with the refueling equipment to preclude pump cavitation prior to completely emptying of all the commodity. The tank is designed for a maximum allowable working pressure of 20 PSIG but operates at atmospheric pressure. Pressure relief is incorporated on both the tanker vessel as well as the GN2 system.

2.4.1.2 Storage

Launch site storage of RP-1 at NASA is primarily done with fixed storage tanks at each launch pad that are used to actually load the rocket within days of launch. RP-1 at NASA is available in 7,000-gallon KSC/CCAFS or vendor tankers and two 20,000-gallon storage tanks.

Kerosene is a relatively low maintenance fuel that allows for easier ground handling and decreased operational costs. In addition, because it is not a cryogenic, or extremely cold, fuel like hydrogen, the propulsion system does not require insulation for propulsion-related ducts, valves, lines and actuators -- saving weight and cost.

2.4.1.3 Transfer

Handling processes for RP-1 at NASA are not high-tech except for the high-performance filters that are used to maintain purity and remove any water that may get into the fuel. NASA KSC's ground handling equipment provides filtration by 1.0-micron absolute filter/water-separator whenever transferring RP-1 into or out of fixed storage tanks. The delivery tankers and pump-cart are not equipped with filters. In addition, because RP-1 is not a cryogenic fuel like hydrogen, handling systems do not require nearly as much insulation for ducts, valves, lines, and actuators.

Much of the equipment used in the petroleum fuel handling industry is certified by third parties. Tanks, valves, pumps, vents, piping systems, and virtually every other tank system component must be third-party-certified for use with flammable and combustible liquids. Among the most common testing organizations are Underwriters Laboratories Inc., Southwest Research, Inc., and Factory Mutual. There are other specialists in certain components, particularly gauging and monitoring systems (e.g., Ken Wilcox and Associates, Midwest Research, Inc., and Vista Corporation).

Other key considerations for handling petroleum fuels include

- Venting – emergency, pressure/vacuum, atmospheric cents may be required
- Pumping
- Piping -- Cathodically protected steel piping, fiberglass, and listed plastic piping may be used underground.
- Antisiphon devices – Simple antisiphon devices should be installed at the high end of the piping at the tank to prevent siphoning in the event of a piping leak.
- Block valves – Block valves are required to control the flow of fuel for maintenance purposes, or in case of a hose or pipe rupture. All block valves must be equipped to relieve excessive pressure back to the tank due to thermal expansion of the product.
- Nozzles.

NASA Pipelines. A distance of 25 feet free of inhabited buildings will be maintained on either side of the pipelines used for the transfer of groups II and III propellants between unloading points and storage areas or between storage areas and points of use.

Kerosene is a relatively low maintenance fuel that allows for easier ground handling and decreased operational costs. In addition, because it is not a cryogenic, or extremely cold, fuel like hydrogen, the propulsion system does not require insulation for propulsion-related ducts, valves, lines and actuators -- saving weight and cost

2.4.1.4 Personnel Protective Equipment

NASA's RP-1 handling procedures do not call for normal personal protection equipment for hydrocarbon fuels, which involves gloves and a face-shield. No other special equipment is required.

2.4.1.5 Disposal

For disposal, NASA first attempts to send off-spec product back to the source for reprocessing. If that were not viable, the next choice would be to send it to the base heat plant and use it in place of fuel oil if the boilers could handle it (most can if set up to burn liquid fuels).

In general, special steps to dispose of kerosene are not required because it can be burned in a range of situations (e.g., heat plants). Kerosene that is contaminated or dirty can be disposed of by a licensed hazardous waste contractor.

2.4.2 Findings and Recommendations

In general, there is only one rocket-grade hydrocarbon fuel used in the United States: RP-1, which is a narrow-cut kerosene that falls within the overall limits of aviation turbine fuel (JP-8 or Jet-A) not counting the additives. Experts contact for this report generally agreed that there is not an overwhelming drive to develop much in the way of advanced detectors, materials, and such that might be needed to enhance hydrocarbon fuels processes. The consensus is that petroleum/hydrocarbon fuel handling is a mature technology area.

Findings and recommendations by technology area are given in the following sections.

2.4.2.1 Transportation

Transportation of petroleum/hydrocarbon fuels for spaceports (primarily RP-1 kerosene) is currently done using industry standard tankers. The key technologies involved in these systems include vents, pumps, valves, and liquid level sensors. All of these technologies have been developed to a high level of maturity by the petroleum handling industry and are implemented by the fuel distributor that delivers the petroleum product.

> Ensure that petroleum fuel supplier uses tankers that conform to industry requirements

2.4.2.2 Storage

Like transporting petroleum products, storing petroleum products is a highly mature industry. Current practices generally conform to best practices. However, areas for incremental improvement include leak detection and leak prevention.

> Employ advanced leak detectors/sensors and industry regulated storage facilities that minimize vessel-related leaks

2.4.2.3 Transfer

Much of the advanced technology being developed for petroleum fuels is being developed in the area of transfer. Automated fueling systems using intelligent sensors and smart, quick disconnects can help remove human operators from the fueling process. Additionally, leak-free disconnects, valves, and piping are key components in petroleum fuel transfer systems. High performance filters are also an area of focus.

> Implement autonomous refueling systems, advanced mechanical devices (disconnects, filters, etc.)

2.4.2.4 Disposal

The disposal measures for kerosene (the primary petroleum fuel used by NASA) are typical for petroleum fuels – off-spec product may be either returned to the supplier for reprocessing or re-purposed on-site (e.g., heat plant). Future spaceport scenarios might include plans to process fuels for quality on site, but the efficiency of the current petroleum fuel infrastructure could be sufficient to handle such scenarios and relive those potential requirements.

Investigate alternate reprocessing or repurposing scenarios.

2.4.3 Critical Technologies

Listed below are technologies that emerged as critical to achieving the Advanced Servicing operational concept for petroleum fuels:

Table 4 Critical Technologies – Petroleum Fuels

P1	• Improved valves and pump handles to prevent releases of volatile hydrocarbons during transfer/fueling operations.
	– Electromechanical disconnects
	– Auto process verification (sensors for connection, reconnection, continuity, flow rate, leak tightness)
P2	• Fully sealed and automated delivery systems can improve both safety and efficiency parameters with regard to operations.
	– Nonintrusive sensors (temperature, pressure, flow rate)
	– Laser vision, ultrasonic position sensors
P3	• Flexible/highly compatible distribution systems for multiple fuels can reduce fueling operations infrastructure.
	– Self-cleaning disconnects
	– Modular fueling systems
P4	• Leak-proof storage tanks reduce propellant losses and minimize some safety concerns.
	– Advanced joining technologies, materials for storage vessels

2.5 Advanced Servicing Technology Roadmaps

Table 5 provides a combined list of all critical technologies RTI identified in the Advanced Servicing Area, and Figure 4 – 6 map these general technologies to the high level Advanced Servicing roadmap from the ASTWG Baseline Study (see Figure 2).

Table 5 Generalized Technologies

	G1	• **Enhanced sensing technologies:**
H1	G1a	- On-chip nanosensors
H1	G1b	- Distributed sensor networks
H1	G1c	- Standard wireless encrypted data links from vehicle to ground hypergol systems
P2, H1, C1	G1d	- Noninvasive sensing of temperature, pressure, flow rate, and other factors to enable feedback on operations without introducing the possibility of leaks
H1	G1e	- Improved response time, accuracy, sensitivity, and maintainability
H1	G1f	- Centralized monitoring systems for leak or concentration detection
C1	G1g	- Low-cost reversible gas sensors with fast response time in broad temperature and concentration range (leak detection, explosive limit, and process level detection) that are not poisoned by other gas species
C1	G1h	- Multiplexed sensors (one controller handle five or more sensors) and distributed sensor networks
C1	G1i	- Reduced false alarm rate flame detectors
C1	G1j	- Integrated flame detectors and flame imaging systems
S1	G1k	– Wireless, noncontact vibration monitoring systems
S2	G1l	– Wireless, noncontact temperature monitoring systems
S3	G1m	– Precision cranes with advanced vibration monitoring/control
C1	G1n	- Standard wireless encrypted data links from vehicle to ground systems
P2	G1o	– Laser vision, ultrasonic position sensors
	G2	• **Optimization of hypergolic fueling carts:**
H2	G2a	- Elimination of intermediate fueling tank
H2	G2b	- Automation through development of standards for interfaces
	G3	• **Improved storage technology:**
H3	G3a	- Development of pre-filled hypergol tanks to enable modular replacement
H3	G3b	- Automated and/or remote loading operations to eliminate fueling carts
H3	G3c	- Simplified low cost manufacturing for on-site, on-demand production of hypergols
	G4	• **Optimized propellant handling plans, procedures, engineering controls, and PPE:**
H4	G4a	- Protective clothing comfortable for outdoor use in accordance with levels of potential exposure
H4	G4b	- Emergency showers, breathing apparatus, and other PPE ready for immediate standby use in hypergolic fueling areas

H4	G4c	- Integral ground systems for containing and mitigating spills
C2, H4	G4d	- Integral static electricity grounding systems
	G5	• **Umbilical technology:**
C2, H4	G5a	- Leak-proof quick connect fittings
C2, H4	G5b	- Machine vision for automated alignment and mating of umbilicals
C2, H4	G5c	- Smart umbilicals that provide automatic process verification for issues such as connection, continuity, flow rate, and leak tightness that are capable of taking corrective action if acceptable conditions are not met
C2	G5d	- Replacing pyro-operated disconnects with electromechanical devices
C2, H4	G5e	- Integral static electricity grounding systems
	G6	• **Propellant System Cleaning**
H5	G6a	- Optimized hypergolic system cleaning and decontamination (e.g., ion exchange resins) such that most waste can be accepted by on-site sewage system or recycled back into process
S5	G6b	- Alternative, environmentally-friendly cleaning solvents and materials: Replace CFC-113 and methyl chloroform cleaners with low vapor pressure cleaners
	G7	• **Storage containers/Propellant Tanks with:**
H6	G7a	- Integrated temperature control
H6	G7b	- Integral pumping and shield gas systems
P4	G7c	– Leak-proof storage tanks reduce propellant losses and minimize some safety concerns.
P4	G7d	– Advanced joining technologies, materials for storage vessels
H7	**G8**	• **Standardization of on-board tanks such that operations are common, routine, and repeatable**
C3	**G9**	• **Cryogenic loading pumps with improved seals, magnetic coupling, and/or the magneto-caloric effect**
C4	**G10**	• **High strength, low cost hydrogen embrittlement resistant alloys for structural applications**
	G11	• **Propellant Manufacture and Distribution**
C5	G11a	– Low-cost modular process for on-site cryogenic production and/or gas liquefaction at the departure point with the ability to quickly ramp up or down output in response to dynamic flight rates
C6	G11b	– Spaceport propellant gas pipeline distribution system similar to the KSC nitrogen pipeline
C7	G11c	– Technologies for low cost liquefaction of boil off (no loss cryogenic storage tank) or the use of boil off for another process
C8	G11d	– Breakthrough in super insulated pipes that would allow efficient cryogenic transfers over long distances (e.g aerogel, multi-layered insulation (MLI), layered composite insulation (LCI), polyimides, and composites)
P1	G11e	- Improved valves and pump handles to prevent releases of volatile hydrocarbons during transfer/fueling operations
P1	G11f	- Electromechanical disconnects

P1	G11g	– Auto process verification (sensors for connection, reconnection, continuity, flow rate, leak tightness)
P2	G11h	– Fully sealed and automated delivery systems can improve both safety and efficiency parameters with regard to operations.
P3	G11i	– Flexible/highly compatible distribution systems for multiple fuels can reduce fueling operations infrastructure
P3	G11j	– Self-cleaning disconnects
P3	G11k	– Modular fueling systems
C9	**G12**	• **Cryogenic densification for future launch vehicles**
	G13	• **Insensitive munitions (propellants)**
S4	G13a	– Reduced reactivity with external hazards (e.g., static charge, mechanical shocks)
S4	G13b	– E.g., Paraffin-based solid fuel to replace existing technology

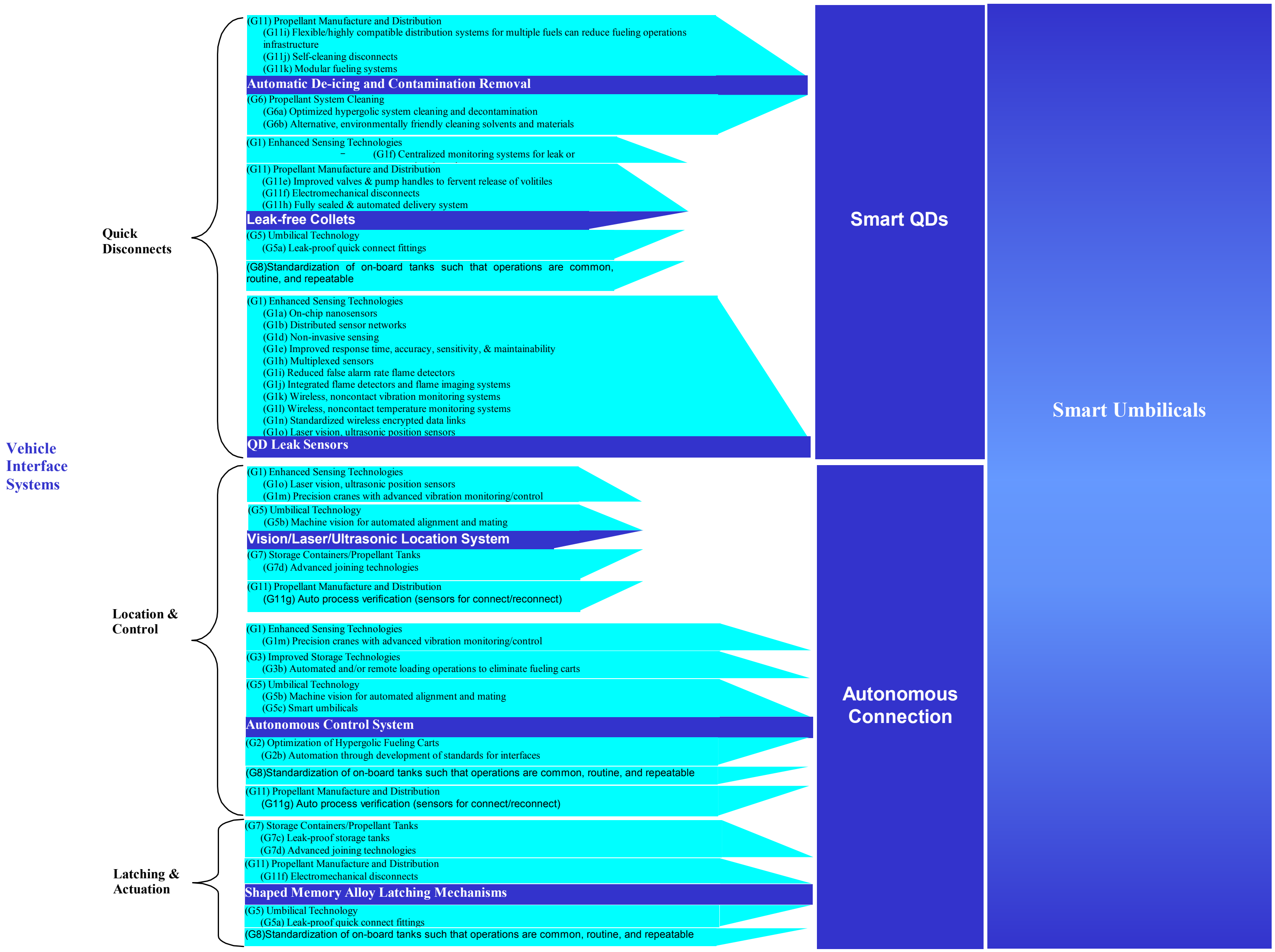


Figure 4 Advanced Servicing Technology Roadmap (1)

Figure 5 Advanced Servicing Technology roadmap (2)

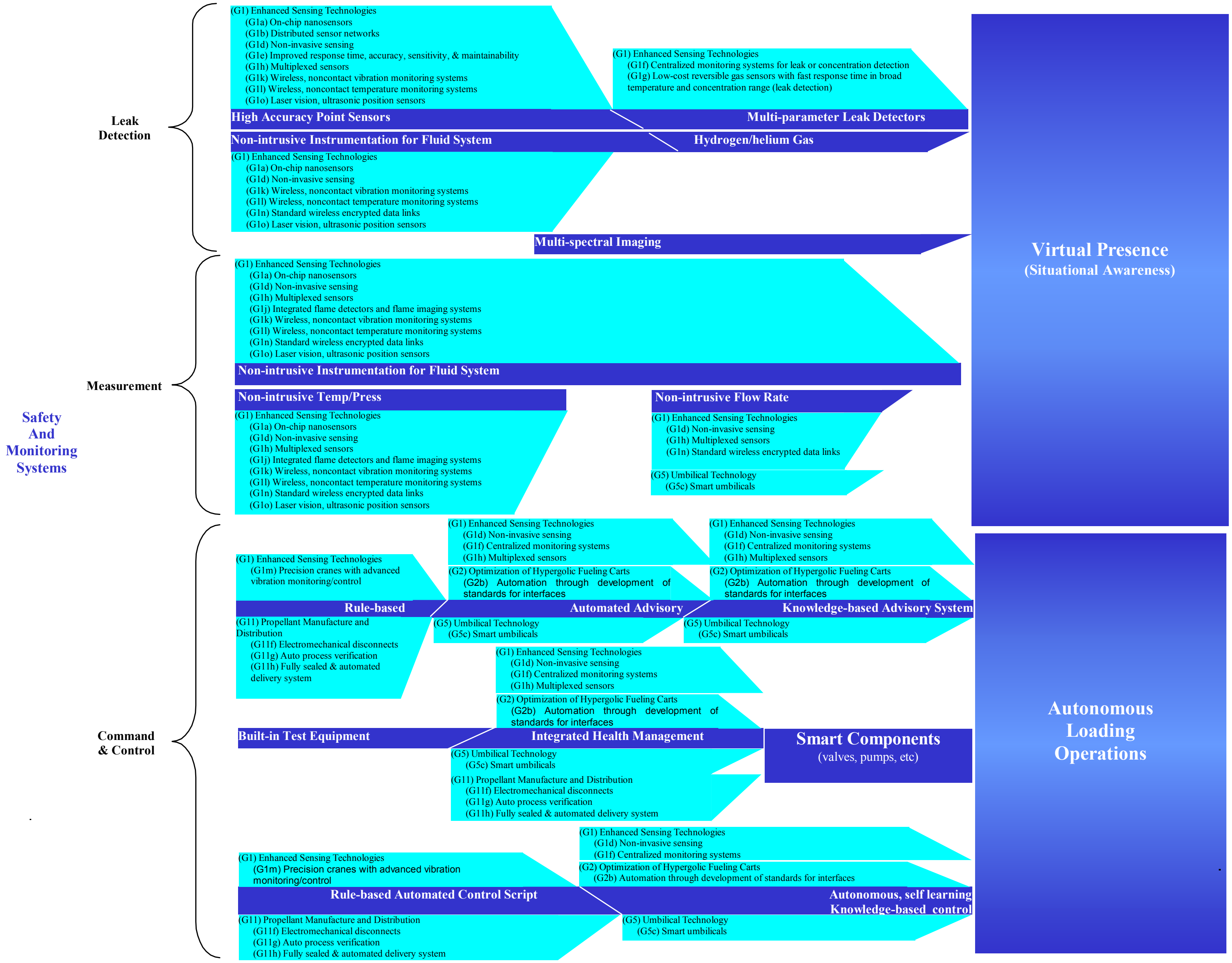


Figure 6 Advanced Servicing Technology Roadmap (3)

3 Dynamic Planning and Scheduling Technology Area

This section documents RTI's research and analysis of the Planning, Documentation, Analysis and Learning TFA, and includes the results from a technology area benchmarking effort, RTI's findings and recommendations, and a list of what RTI deems to be the critical technologies for this TFA. These critical technologies are then mapped to the ASTWG high level TFA roadmap depicted in Figure 3.

Planning is that element of spaceport operations that relates to defining user requirements and matching those requirements to spaceport services. Planning is the preparation of actions (movements) in the broadest sense of the word: setting a goal; determining actions to achieve this goal; and sequencing these actions. It takes into account the current situation, available resources, changing information, …(many constraints).[1] Some constraints are hard (i.e. mission critical or physical limits) and some are soft (e.g. preference for convenience), and they differ per location and situation.

The scheduling task is to allocate known activities to available resources and time - respecting capacity, precedence (and other) constraints. Scheduling is a natural by-product of planning. Although the availability of resources is considered during planning, the actual reservation of these resources occurs under the scheduling umbrella and encompasses all phases of operations, maintenance and, possibly, training. Future space transportation systems must be able to provide the same degree of safety and reliability that current systems do, but at greatly reduced costs. Automated scheduling of operational resources and maintenance activities can reduce turn around times for these systems, thereby reducing costs. (by reducing the size of the required fleet). In order to accomplish this, a performance summarization must be efficiently communicated during flight so that the logistics elements can be initiated prior to landing and/or to generate a maintenance schedule for the next ground processing cycle.

3.1.1 Benchmarking

Initially, a benchmarking effort was undertaken to baseline the Planning and Scheduling processes and technology used in a variety of industries (aerospace and non-aerospace). Specifically, industries that require, develop or employ real-time planning, data management and resource scheduling were targeted. Originally it was envisioned that planning and scheduling would be addressed as independent functions; however, due to their interdependencies and similar technology requirements, they are treated as one entity in this research. Appendix A - Research Notes contains the raw data generated by RTI during this effort.

It was found that in the aviation industry, automated tools were identified in the flight crew management area. For example, data relative to crew flight times are aggregated, to ensure that mandatory crew rest is met.[2] Additionally, the crew is able to access/update their schedule inputs and assignment information (e.g. hotel reservations) over the web. Flight information is automatically updated via a link to the Department of Transportation Volpe center. No true aviation "facility" scheduler was identified. There is significant work relative to databasing of resource information (e.g. size, location, and capacity information for operational planning).

Many universities use automated schedulers that are web based to dynamically schedule and deconflict facilities (laboratories, classrooms, etc.)[3,4]; however, these schedulers are stand-alone systems only (i.e. they are not integrated with other resources). They do, however, track costs and perform automatic conflict detection/resolution.

The Medical field uses relational database technology to manage employee credentialing information, employee availability, etc; however, data input and schedule composition is manual.[5] Also, within the medical community, there is more emphasis on database/human-in-the-loop data management of facility schedules.

Within the Air Force, scheduling of a worldwide network of limited resources to meet diverse mission needs (e.g., scheduling time on the antennas comprising the Air Force Satellite Control Network) is currently accomplished manually, using a very time consuming and personnel-intensive method. However, within the operations centers, the ACE Visual Scheduler[6] enabled the Center for Research Support (CERES) to instantaneously prioritize and deconflict their local communication resources and assign each scheduled contact to an operational string.

Relative to in-flight status of the vehicle, engine manufacturers have installed sensors and on-board computers that monitor engine performance and provide fault diagnostics during flight. This information is stored on-board and may also be sent to the factory for detailed analysis. Wireless downlink of data from the plane occurs intermittently due to bandwidth and cost considerations. They do employ automated trend analysis tools; however, there does not appear to be any automated link between this data and any maintenance schedules.

At Kennedy Space Center, a recent upgrade to the old Complex Control System (CCS), called the KCCS (Kennedy Complex Control System), controls and monitors power, HVAC, potable water and wastewater, compressed gas distribution, and other facility- and utility-related systems throughout KSC. KCCS is a flexible system based entirely on commercial off-the-shelf (COTS) hardware and software and offers significant cost savings to NASA. Although restricted in its present deployment, the COTS-based KCCS was also selected for its ability to communicate with newer technology sensors and “smart” devices using a large variety of communication formats including Ethernet, LONWORKS, MODBUS, MODBUS/TCP, PROFIBUS, DEVICENET, SERIPLEX, and other common industrial field buses. The system can also communicate with equipment made by Andover Controls. In addition, the system can accept existing commercial instrumentation outputs such as analog voltages, current loop, contact closure, and other standard quantities. Currently there are approximately 10 active installations of KCCS and the plan is to expand the system to include measurements for launch pad fire sprinkler and water deluge systems. Relative to work flow management at KSC, the Logistics Operations Directorate’s Materials Science Division (MSD) implemented the WTS (Work Tracking System) in 1998. This system performs the following:

- Automatic e-mail to customers with status changes, such as job on hold, job complete
- Automatic notification to MSD personnel for new jobs and status updates
- Ad hoc reporting
- Security and access control with password and firewall
- Automatic file transfer
- Transaction logging
- Electronic signatures
- Add and display job documents including pictures and reports
- Job splitting
- Equipment calibration tracking
- Part/material tracking

Additionally, NASA has the Ground Processing Scheduling System (GPSS), used to manage shuttle processing at KSC. GPSS is based on circa mid-nineties artificial intelligence technology.

In general, RTI found that many governmental agencies (DOD,DOE, NASA) have addressed the scheduling problem at varying levels; however, none have attacked the “real-world” problem.

For the application of dynamic planning systems to real-world problems, the incorporation of metrics is a fundamental feature. The following table provides a benchmark of these metrics and their application to various non-aerospace developed systems.

Table 6 Dynamic Planning Systems and Metrics

Metrics
Overall Goal:
• Optimization - Complex Functions *(e.g., maximizing monetary outcome)*
• Optimization - Monotonic Functions *(e.g., minimizing power use)*
• Satisfaction *(e.g., that the resources are not overloaded)*
Temporal Properties/Relationships:
• Temporal Planning *(e.g., involving scheduling)*
• No Temporal Planning *(e.g., STRIPS planning)*
Plan Structures:
• Dynamic Construction *(e.g., like in partial-order planning)*
• Maximal/Disjunctive Graphs *(e.g., Graphplan representations or CSPs)*
Search Paradigm:
• Local Search *(e.g., GSAT or simulated annealing)*
• Refinement Search *(e.g., partial-order planning)*
Integration:
• Integrated System *(e.g., respecting resource bottlenecks within planning)*
• Separate Solvers *(e.g., successive planning and scheduling phases)*

Systems
System Name: **ASPEN planner/scheduler** [7]
Attributes: Optimization - Complex Functions Temporal Planning Dynamic Construction Local Search Integrated System
System Name: **Cooperative Intelligent Real-time Control Architecture** [8]
Attributes: Satisfaction Temporal Planning Dynamic Construction Refinement Search Separate Solvers
System Name: **Extensible Universal Remote Operations Planning Architecture**[9]
Attributes: Satisfaction Temporal Planning Dynamic Construction Refinement Search Integrated System
System Name: **The EXCALIBUR agent's planning system** [10]
Attributes: Optimization - Complex Functions Temporal Planning Dynamic Construction Local Search Integrated System
System Name: **The LPSAT engine's application to resource planning** [11]
Attributes: Satisfaction No Temporal Planning Maximal/Disjunctive Graphs Refinement Search Separate Solvers

System Name: **MO-GRT** [12]
Attributes: Optimization - Monotonic Functions No Temporal Planning Dynamic Construction Refinement Search Integrated System
System Name: **O-Plan** [13]
Attributes: Satisfaction Temporal Planning Dynamic Construction Refinement Search Integrated System
System Name: **PYRRHUS**[14]
Attributes: Optimization - Monotonic Functions No Temporal Planning Dynamic Construction Refinement Search Integrated System
System Name: **RealPlan** [15]
Attributes: Satisfaction No Temporal Planning Maximal/Disjunctive Graphs Refinement Search Integrated System or Separate Solvers
System Name: **RIPP** [16]
Attributes: Satisfaction No Temporal Planning Maximal/Disjunctive Graphs Refinement Search Integrated System

System Name: **TP4**[17]
Attributes: Optimization - Monotonic Functions Temporal Planning Dynamic Construction Refinement Search Integrated System

3.1.2 Findings and Recommendations

Most of this effort focused on Dynamic Scheduling for the ASTWG operational concept. An emphasis was placed on discovering novel and breakthrough practices and technology that would be enabling for the ASTWG vision for future spaceport operations.

"There have been some large successes in the application of automated scheduling … However, the reality remains that most scheduling tasks that could potentially benefit from automated scheduling are performed manually."[1] This is mainly due to oversimplification of the real-world problem, lack of standard interfaces between different scheduling algorithms, the inability to handle large sets of diverse data, the fact that complex/optimized algorithms take too long to "compute" and the lack of standard benchmarking/validation that the scheduler is satisfying requirements.

Additionally, RTI found that though there are pockets of innovation, no systems engineering approach has been employed for the overall problem. These 'pockets" have addressed limited domain areas (e.g. facilities or people), but have not integrated into a cohesive system-wide solution to the problem. This is partly because the Artificial Intelligence (AI) experts have traditionally worked separately from the Operational Research (OR) groups and the metaheuristics people (genetic algorithm). However, this is starting to change: the very first interdisciplinary scheduling conference was held in England just this past summer (Multidisciplinary International Conference on Scheduling : Theory and Applications Nottingham, UK, August 2003).

Planning and Scheduling have traditionally been very labor-intensive tasks with significant time lag between an event that changes the plan/schedule and the actual update of the schedule. Due to the time lag, very little schedule optimization has been feasible. Additionally, interrelated schedules have typically been generated and updated in a vacuum and then coordinated "after the fact". RTI advocates that

[1] David J. Montana, BBN Technologies

to succeed in this area, researchers must focus on all the elements of a real-time planning and scheduling system as depicted in Figure 7.

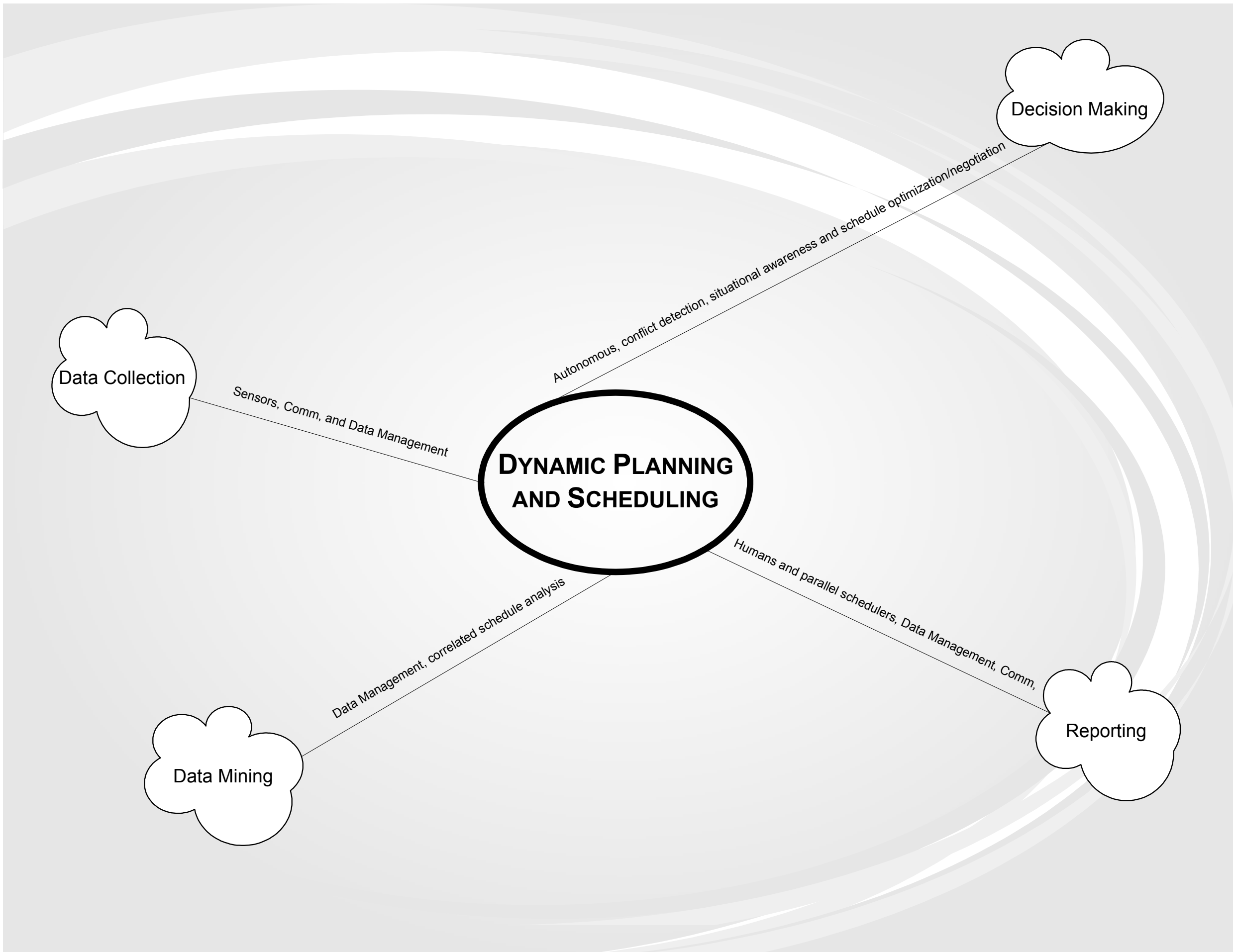


Figure 7 Dynamic Planning and Scheduling System Elements

Where,

Data Collection – receipt of voluminous data from a variety of sources (people, sensors, other schedulers, etc.) input is either automated or manual. Major data elements are vehicle/payload, worker, spaceport GSE/instrumentation, and facilities. Data items of interest included:

- Status/Availability
- Planned Activity
- Capability
- Weight / priority

Data Mining - look for trends or anomalies

Decision Making – real-time -optimized, weighted
Reporting – Update schedules, send out appropriate notifications, automatically export appropriate information to planning and financial applications.

The following list highlights the recommended attributes of the system:

- Intelligent autonomous system
- Automated risk management
- Automatic data reduction
- Full situational awareness
- Real-time data transfer to all interested entities (e.g. crew or "other" automated scheduler)
- High speed communication
- Automated plan generation based on user responses to support questions
- Constraint satisfaction with optimization
- Knowledge-based planning that integrates plans across all spaceport resources and/or all spaceports
- Automated requirements generation and tracking
- Cost analysis associated with the plan
- Real-time re-planning
- Continuous optimal throughput
- Automated pricing and billing including rates, calculations, invoicing, payments and accounts receivable
- Autonomous conflict detection/resolution

3.1.3 Critical Technologies

The following text boxes contains the critical technologies RTI has identified for the Dynamic Planning and Scheduling system elements defined in the previous sections:

- **Data Collection/storage Methods**
    - Mass Storage Memory
    - Non intrusive video data collection
    - Mobile data input devices
        - Wearable computers
        - Hand-held, wireless data input devices
        - Wireless Sensor Technology

- **Data Mining Methods**
    - Automated/integrated health (Facility, GSE, Worker, Customer vehicle,.) monitoring with logistics (supply, cost, …)tracking
    - Multidimensional mining algorithms
    - Automatic pattern recognition
    - Expert systems
    - Neural network
    - Dynamic and self-learning system
    - Cognitive and artificial intelligence
    - Integration of heterogeneous databases

- **Decision Making/Optimization** methods/algorithms
  - Multi-objective optimization/evaluation function
    - Linear combination of weighted criteria
    - Chaos theory techniques
  - Simulations
    - Simulated Annealing (SA)
    - Genetic algorithms (a form of random search)
    - Artificial Neural Networks (ANNs)
    - Evolutionary Computation (EC)
    - Discrete event simulators
    - Continuous event simulators
    - Mixed-mode simulators
    - Multi-agent simulation of complex systems
    - Prediction-based simulations
      - Chaos theory (qualitative study of unstable aperiodic behavior in deterministic nonlinear dynamical systems) "A system can be random in the short-term and deterministic in the long term"[18]
      - Heuristic based
  - Planning and negotiating algorithms
    - Decomposition-based
    - Fully autonomous intelligent agents (Agent-based)
    - Backward chaining[19]
  - Dynamic Scheduling Algorithms
    - Tabu search
    - Simulated annealing techniques
    - Genetic algorithms
    - Standard benchmarking that the schedule is satisfying requirements
    - Standard interfaces between scheduling algorithms
    - Search-based solvers

- Plan/Schedule **Reporting**
    - Human-machine interfaces
        - High-volume/speed processing and display technologies
        - Holographic/3-d views
        - Enhanced cybernetic interfaces
    - Communication
        - Cell Phones
        - Wireless Personal Area Networks
        - High Speed Communication Technology
        - High speed digital data links (e.g. Mode S or ACARS)
        - Graphical, alphanumeric, voice and computer autonomous modes of information transfer
        - Dynamic network reconfiguration
            - Genetic algorithms
            - Collaborative mechanism: (e.g. Priority of access is given to Bluetooth for voice packets and WLAN is given priority for transmitting data using the TDMA (Time division multiple access) solution
            - Non collaborative solution
        - Standard protocols
        - Blind network development (i.e. plug and play network)
        - Network traffic flow optimizer schemes
            - Feedback algorithms
            - User prioritization schemas
            - Multi-user diversity throughput enhancement

3.2 Dynamic Planning and Scheduling Technology Roadmaps

Figures 8 and 9 map the critical technologies identified in the previous section to the high level Planning, Documentation, Analysis and Learning roadmap from the ASTWG Baseline Study (see Figure 3).

Figure 8 Planning and Documentation Technology Roadmap

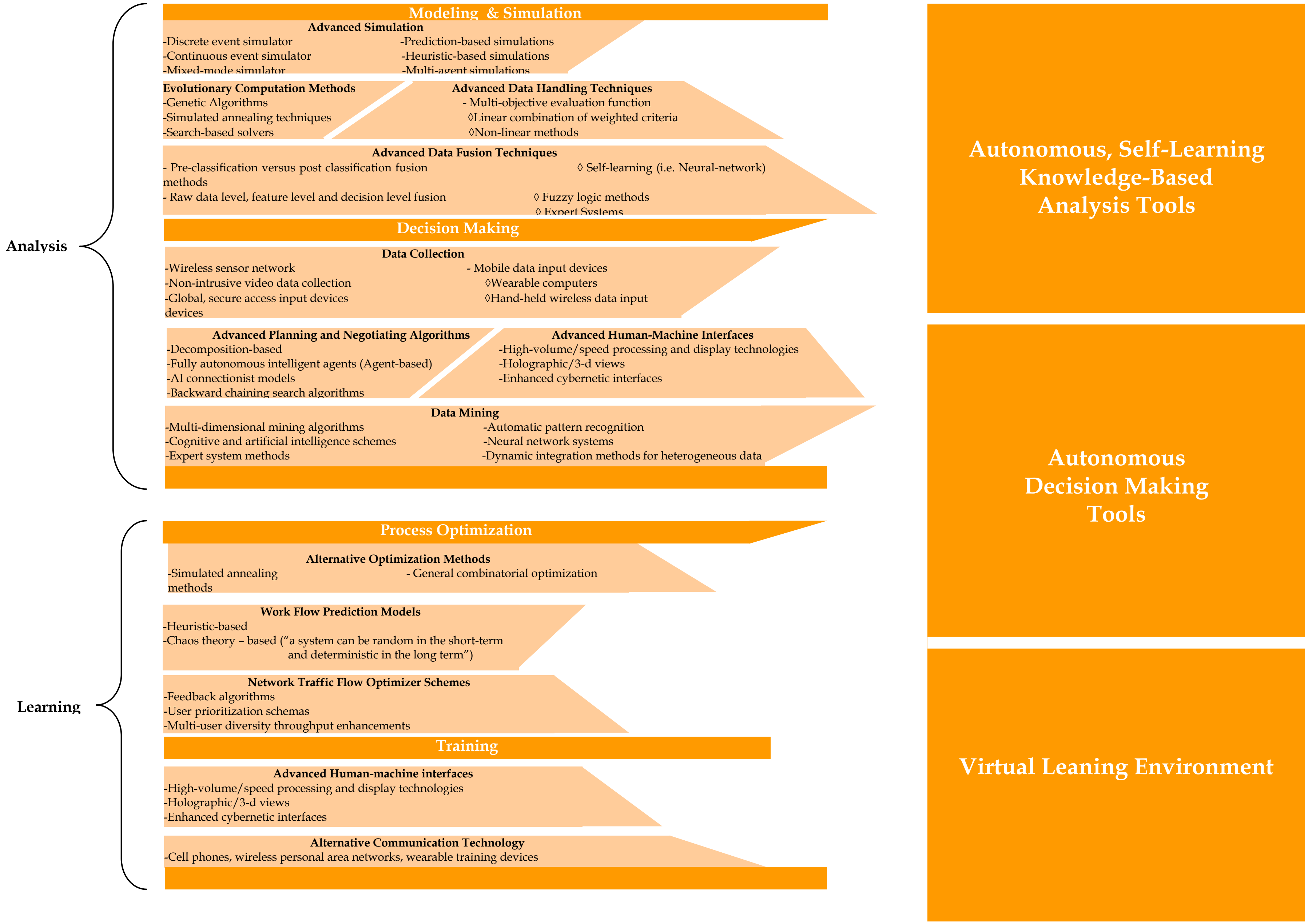


Figure 9 Analysis and Learning Technology Roadmap

4 Space Industry Standards Benchmark

Although not an actual technology, throughout all of the ASTWG technology focus meetings, the need for standardization in order to achieve the ASTWG vision for spaceport operations was voiced by stakeholders from every community. Standards are generated at several levels: organizational (e.g. company or government organizations), industrial, national and international level. RTI researched standards at the international level and then moved into the sublevels due to the global attributes of the ASTWG vision.

4.1 International Standards Organizations

EDItEUR - The European group for electronic commerce in the book and serials sectors. EDItEUR has developed and maintains ONIX an international standard for representing and communicating book industry product information in electronic form.

IETF - The Internet Engineering Task Force (IETF) is an international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet.

World Wide Web Consortium - Known popularly as the **W3C**, the World Wide Web Consortium is an international industry consortium founded in 1994 to develop common standards for the World Wide Web, such as XML, SMIL, and CSS. The Laboratory for Computer Science at MIT hosts W3C in the U.S. An example of their activities is the Wireless Application Protocol (WAP). WAP is a set of standards that enables a wireless phone or other mobile device to browse Internet content optimized for wireless phones.

ISO – The major international standards organization, ISO (International Organization for Standardization), is a world-wide federation of national standards groups representing 135 countries. ISO's mission is to promote the development of global standards in order to promote international trade of goods and services. ISO was founded in 1946, under the auspices of the United Nations, and is headquartered in Geneva, Switzerland. Figure 10 depicts the organizational structure of ISO.

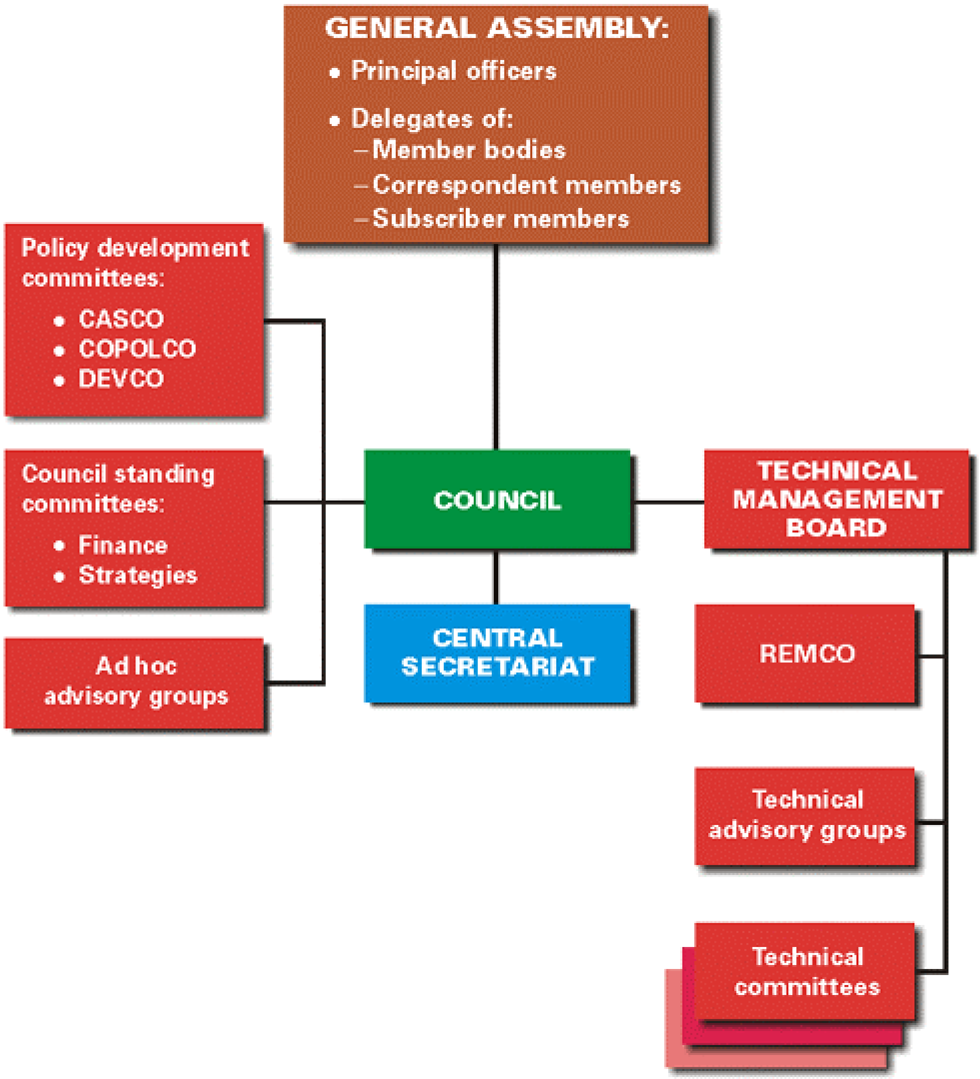


Figure 10 ISO Structure[20]

There are 225 Technical Committees (TC) in ISO at the present time. Appendix C - ISO Technical Committee List contains a complete listing of these TCs. In addition to developing new standards, technical committees are responsible for maintaining previously developed standards.

The following list identifies the Technical committees that RTI advocates are directly, related to the space industry:

JTC 1	Information technology
TC 2	Fasteners
TC 10	Technical product documentation
TC 11	Boilers and pressure vessels

TC 20	Aircraft and space vehicles
TC 30	Measurement of fluid flow in closed conduits
TC 46	Information and documentation
TC 67	Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries
TC 94	Personal safety -- Protective clothing and equipment
TC 96	Cranes
TC 98	Bases for design of structures
TC 101	Continuous mechanical handling equipment
TC 104	Freight containers
TC 115	Pumps
TC 131	Fluid power systems
TC 135	Non-destructive testing
TC 138	Plastics pipes, fittings and valves for the transport of fluids
TC 142	Cleaning equipment for air and other gases - STAND BY
TC 144	Air distribution and air diffusion - STAND BY
TC 153	Valves
TC 158	Analysis of gases
TC 159	Ergonomics
TC 172	Optics and photonics
TC 178	Lifts, escalators, passenger conveyors
TC 184	Industrial automation systems and integration
TC 185	Safety devices for protection against excessive pressure
TC 197	Hydrogen technologies
TC 203	Technical energy systems
TC 204	Intelligent transport systems
TC 209	Cleanrooms and associated controlled environments
TC 220	Cryogenic vessels

Joint Technical Committee one (JTC1) and Technical Committees 20, 197, 209 and 220 are of the most immediate interest to the ASTWG vision.

It should be noted that the International Electrotechnical Commission (IEC) joined with ISO to create JTC1. This ISO/IEC Joint Technical Committee was created to ensure these two major standards organization provided consistent oversight in the field of information technology.

ISO/TC 20, and the US standards developers relation to it, will be further defined in subsequent sections; however, in general, TC20 is responsible for the standardization of materials, components and equipment for construction and operation of aircraft and space systems as well as the equipment used in the servicing and maintenance of these vehicles. This includes aeronautic and aircraft, launch systems and satellites, specialized ground equipment, and basic elements of international air commerce such as air cargo. Work items focus on standardization for the design, construction, test and evaluation, operation, maintenance and disposal of components, equipment and systems of aircraft and space systems, including issues related to safety, reliability and the environment.[21]

4.2 How International Standards Are Developed

In the United States, representatives from the private and public sectors develop national standards through a voluntary consensus process. National standards rarely become law and their adoption by businesses and other entities is voluntary. This is not the way it works for a majority of the world; standards development is generally a function of the national government and standards frequently become law. Therefore, at the international level of standards development, individual countries are the key members.

In any standards development activity when an idea or a need for a standard is identified and approved work begins. International Standards are developed by ISO technical committees (TC) and subcommittees (SC) by a six step process:

Stage 1: Proposal stage
Stage 2: Preparatory stage
Stage 3: Committee stage
Stage 4: Enquiry stage
Stage 5: Approval stage
Stage 6: Publication stage

The new work item (NWI) proposal must be approved by the TC's or SC's participating members; at least five members must indicate a willingness to take an active role in the development of the standard. During its life, the new work item will take on several designations (working draft WD, committee draft CD, draft international standard DIS, and final draft international standard FDIS).

Once a new work item has been approved, it is either assigned to an existing work group within a subcommittee or a new work group is created. Those who participate in these working group sessions are referred to as "individual experts." The goal in these meetings is to advance positions, solve technical problems, share test results, and arrive at a working draft that reflects a general consensus. An individual expert is named as the project leader, and this individual is responsible for maintaining the draft.

When the working draft is completed and approved by the working group, it is then forwarded to the parent subcommittee. The resulting document, a CD, is then balloted by the subcommittee members. Depending on the complexity and interest of members, the ballot process may go smoothly with very few comments and no negative votes, or there may be concerns and issues that result in strong positions and negative votes.

The comments and negative ballots are resolved either in meetings or via correspondence, with the project leader overseeing all of the changes. Unanimity is not always possible, but it is important that all comments be considered. It may be necessary to prepare another committee draft and ballot it. Once the required number of votes is achieved, the committee draft is registered at ISO headquarters as a draft international standard (DIS).

If the NWI is tied to another documented standard or process (e.g. a standard developed by another organization), it is possible to omit certain stages of the six-stage process. This is known as a "fast-track procedure" and the document is submitted directly for approval as a Draft International Standard (DIS) - stage 4 or, if it has been developed by an international standardizing body recognized by the ISO Council (e.g. IEC), it will be submitted as a Final Draft International Standard (FDIS) –stage 5.

4.3 US Involvement In International Standards

To provide a channel to the international standards process, standards developers in the US belong to the American National Standards Institute (ANSI). The Institute is the only US representative and dues-paying member of the International Organization for Standardization (ISO). As a founding member of ISO, ANSI plays a strong leadership role in its governing body.

4.3.1 US Standards Organizations

The American National Standards Institute (ANSI) is the primary national federation of standards developers in the US. Its goal is to enhance the global competitiveness of US business and the American quality of life by promoting and facilitating voluntary consensus standards and ensuring their integrity. Although ANSI itself does not develop national standards, ANSI accredits some 400 organizations as national standards developers. Essentially, ANSI provides all interested US parties with the setting to create voluntary standards based on the fundamental principles of consensus, due process and openness. The Institute ensures that access to the standards process, including an appeals mechanism, is made available to anyone directly or materially affected by a standard that is under development. Thousands of individuals, hundreds of companies, several government agencies and other organizations, such as labor, industrial and consumer groups, voluntarily contribute their knowledge, talents and efforts to standards development. Published standards documents are of four kinds: Standards, Recommended Practices, Guides, and Special Project Reports.

The ANSI standards development process has four elements:

- Consensus on a proposed standard by a "consensus body" that includes representatives from materially affected and interested parties
- Broad-based public review and comment on draft standards
- Formal consideration of and response to comments submitted by voting members and by the reviewing public
- Incorporation of approved changes into a draft standard
- Right to appeal by any participant that believes that due process principles were not sufficiently respected during the standards development

In addition to facilitating the formation of standards in the US, ANSI promotes the use of US standards internationally, advocates US policy and technical positions in international and regional standards organizations and encourages the adoption of international standards as national standards where these meet the needs of the user community.

The key space-industry oriented standards developers accredited by ANSI are:

AIAA - American Institute of Aeronautics and Astronautics
The AIAA Standards Program consists of the development and publication of scientific and technical standards and data. The technical scope of these standards documents covers all areas of interest to AIAA Technical Committees.[22] This includes systems, components, materials, products, technologies, methods, and practices in aerospace applications. Standards will cover such topics as health, safety, design, testing, construction, maintenance, performance, environment, and operation of aerospace devices, equipment, and methods. AIAA committees on standards activities[23] are listed below:

<u>Aerodynamic Decelerator Systems</u>

> *Scope:* Standardization for the development and application of all types of aerodynamic decelerators.
> *Published Document:* Standard for Aerodynamic Decelerator and Parachute Drawings (ANSI/AIAA S-017A-2000)
> *Chairman:* Ms Elsa Hennings, Naval Air Warfare Center

<u>Astrodynamics</u>

> *Scope:* Standardization in the branch of space science and engineering dealing with the motion of artificial bodies in space.
> *Published Document:* Recommended Practice for Astrodynamics Concepts,

Quantities, and Symbols - Part 1 (ANSI/AIAA R-064-1994)

Current Projects: Recommended Practice for Astrodynamics Concepts, Quantities, and Symbols - Part 2
Chairman: David Vallado, Raytheon

Atmospheric Flight Mechanics

Scope: Standardization for the aerodynamic performance of vehicles moving through planetary atmospheres; serve as the SCAG for ISO TC20/SC3, Flight dynamics.
Current Projects: Ongoing review of the several parts of ISO 1151 for possible adoption in the USA and modification of a Draft International Standard on atmospheric turbulence.
Published Documents: Recommended Practice for Atmospheric and Space Flight Vehicle Coordinate Systems (ANSI/AIAA R-004-1992)
Chairman:

Atmospheric & Space Environments

Scope: Standardization of the descriptions of the properties of atmospheric and space environments with emphasis on scientific models.
Published Documents: Guide to Reference and Standard Atmosphere Models (ANSI/AIAA G-003A-1996)
Special Project: Contemporary Models of the Orbital Environment (SP-069-1995), Guide to Global Aerosol Model (G-065-1999), Guide to Ionospheric Reference Models (G-034-1998), Guide to Modeling the Earth's Trapped Radiation Environment (G-083-1999)
Chairman: Dr. Shu T. Lai, USAF Research Laboratory

Computational Fluid Dynamics

Scope: Standardization in the field of computational fluid dynamics for the purpose of promoting improvement in efficiency and productivity.
Published Documents: Guide to Verification and Validation of Computational Fluid Dynamics Simulations (G-077-1998)
Chairman: Mr. Raymond Cosner, Boeing Phantom Works

Guidance, Navigation, & Control

Scope: Standardization for the interfaces between GN&C subsystem components and software and between GN&C subsystems and other subsystems.
Current Projects: Preparation of a Standard for Spacecraft Guidance, Naviagation, and Control System Information Interfaces (S-076)
Chairman: Mr. Dorian Challoner, Boeing Satellite Systems

Life Sciences & Systems

Scope: Standardization related to the requirements for humans in development and operation of aerospace systems.
Current Projects: Guide: Human Factors Taxonomy (G-048) and preparation of a Guide for Human Physiological Measurements
Published Documents: Guide for Human Performance Measurements (ANSI/AIAA G-035A-2001)
Chairman: Dr. Valerie Gawron, Veridian, Calspan Operations

Intelligence Systems

Scope: Standardization which will promote the use of artificial intelligence and knowledge based systems with emphasis on vocabulary, life cycle development, validation & verification, and software tools.
Current Projects: Guide to Vocabulary for Artificial Intelligence (G-030) and preparation of a Guide for Validation and Verification in Artificial Intelligence (G-033)
Published Documents: Guide to Life Cycle Development of Knowledge Based Systems (ANSI/AIAA G-031-92)
Chairman:

Software Systems

Scope: Standardization of application specific characteristics of computer software originating in aerospace.
Published Documents: Guide for Reusable Software: Assessment Criteria for Aerospace Applications (AIAA G-010-1993), Guide for the Preparation of Operations Concept Documents (ANSI/AIAA G-043-1992), Recommended Practice for Software Reliability (ANSI/AIAA R-013-1992)
Chairman: Mr. Ron Kohl, Intermetrics, Inc.

Electric Propulsion

Scope: Standardization of vocabulary and performance statements for spacecraft electric propulsion systems.
Current Project: Recommended Practice for Electric Propulsion Mission Analyses (R-006)
Chairman:

Hydrogen

Scope: Standardization of handling, storage, and use of hydrogen in gaseous liquid and slush form.
Current Project: Guide for Hydrogen System Design, Materials Selection, Operations, Storage, and Transportation (G-095)
Chairman: Stephen S. Woods, Honeywell, Inc.

Liquid Propellants

Scope: Standardization of handling, storage, and use of liquid propellants.

Current Project: Guide for Safety Aspects of Hypergols – Hydrazine (G-084A)

Published Documents: Special Report: Fire, Explosion, Compatibility and Safety Hazards of Hypergols – Hydrazine (SP-084-1999), Special Report: Fire, Explosion, Compatibility and Safety Hazards of Hypergols – Monomethylhydrazine (SP-085-1999), Special Report: Fire, Explosion, Compatibility and Safety – Nitrogen Tetroxide (SP-086-2001)

Chairman: Stephen S. Woods, Honeywell, Inc.

Solid Rockets

Scope: Standardization of design and application principles for solid rockets.

Current Projects: Recommended Practice for Safety during Solid Rocket Propulsion System Ground Operations (R-054)

Chairman:

Communication Satellites

Scope: Standardization of design and functional issues addressing both satellite design and communication protocols.

Current Project: Guide to Telemetry, Tracking, & Control Requirements for Communication Satellites (G-068)

Chairman:

Orbital Debris

Scope: Standardization of methods for mitigating the generation of orbital debris including debris flux models and vocabulary; and coordinate the orbital debris related activities of other AIAA Committees on Standards.

Published Document: Special Report: Orbital Debris Mitigation: Technical, Legal, and Economic Aspects (SP-016-1992), Special Report: MEO/LEO Constellations: U.S. Laws, Policies, and Regulations on Orbital Debris Mitigation (SP-016-2-1999)

Chairman: Ms Pamela Meredith, Law Offices of Pamela Meredith

Serviceable Spacecraft

Scope: Standardization of the architecture and interfaces necessary for effective spacecraft servicing.

Published Documents: Guide for Berthing/Docking/Grasping Interfaces for Serviceable Spacecraft (AIAA G-056-1992) and Guide for Serviceable Spacecraft Utility Connector Interfaces (AIAA G-072-1995)

Current Projects: Revision to Guide to Design for On-Orbit Spacecraft Servicing (AIAA G-042-1991)

Project Leader: Steven Leete, NASA/GSFC

Chairman: Mr. Wally McCoy, Washington Square Associates

<u>Space Automation & Robotics</u>

Scope: Standardization for performance parameters related to the use of automation and robotics in space missions with emphasis on interfaces, reliability, and life cycle design. Current Project: Guide for the Design of System Elements Supporting an Autonomous Rendezvous & Docking Capability (G-047)

Published Documents: Standard Vocabulary for Space Automation & Robotics (AIAA S-066-1995).

Chairman:

<u>Space Launch Systems</u>

Scope: Standardization of vocabulary, interfaces, safety practices, mission profiles, and other system design aids which will promote commercialization of space transportation.

Published Documents: Standard for Commercial Launch Safety (ANSI/AIAA S-061-1998), Recommended Practice for Reporting Earth-to Orbit Mission Profiles (AIAA R-060-1993), and Guide to Terminology for Space Launch Systems (ANSI/AIAA G-057-1994)

Chairman:

<u>Space Operations and Support</u>

Scope: Standardization for the training, servicing, and logistical issues associated with space operations and support.

Current Projects: Guide: A Recommended Taxonomy of Terms Associated with Reusable Software in Aerospace Operations (G-067), Standard Life Cycle Cost Model for Space Systems (S-062), and Guide to a Standard Framework for Satellite Control Operations (G-068)

Published Documents: Recommended Practice for Human-Computer Interfaces for Space System Operations (ANSI/AIAA R-023A-1993)

Chairman:

<u>Design Engineering</u>

Scope: Standardization of basic design principles to support other Committees on Standards.

Published Documents: Recommended Practice for Mass Properties Control for Satellites, Missiles, and Launch Vehicles and Recommended Practice for Spacecraft System Design in SI Units (AIAA R-021-1992)

Co-chairmen: Dr. Alvin Sheffler, Motorola and Mr. Roger Belt, Boeing

<u>Ground Test</u>

Scope: Standardization for the test and evaluation of aerospace equipment in ground-based facilities.

Current Projects: Guide for Assessing Experimental Uncertainty, Supplement

to AIAA S-071A-1999 (G-045), Recommended Practice for Wind Tunnel Testing (R-092)
Published Documents: Standard for the Assessment of Experimental Uncertainty with Application to Wind Tunnel Testing (AIAA S-071A-1999)
Chairman: Dr. Susan T. Hudson, Mississippi State University

<u>Materials</u>

Scope: Standardization of methods for the systematic application of materials in aerospace applications.
Current Project: Recommended Practice for In-Space and Simulated Atomic Oxygen Exposures and Analyses (R-046)
Chairman:

<u>Reliability</u>

Scope: Standardization of methods for the systematic development of reliable systems, including acquisition management issues.
Published Documents: Recommended Practice for Parts Management (ANSI/AIAA R-100A-2001)
Chairman: Mr. John Gartin, Demac Enterprises

<u>Space Electronics</u>

Scope: Standardization of the methods for specifying the performance of electronic systems and subsystems in space environments.
Published Document: Mil-Std-2036 (Space), General Requirement for Electronic Equipment Specifications - Space Requirements
Chairman:

<u>Structures</u>

Scope: Standardization to support design of aerospace structures, including future requirements for loads, materials, processes, configurations, life cycles, and tests.
Current Project: Guide to the Uses of Aerospace Pressure Vessels Standards (G-082), Standard for COPVs with Non-Metallic Liners (S-088), Standard for Composite Solid Rocket Motor Cases (S-089), Standard for Composite Pressurized Structures (S-093), and Revision of S-001-1991
Published Document: Standard Terminology for Space Structures (ANSI/AIAA S-001-1991), Standard for Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components (ANSI/AIAA S-080-1998) and Standard for Space Systems - Composite Overwrapped Pressure Vessels (ANSI/AIAA S-081-2000).
Project Leader, S-001B: Dr. Michael Lou, JPL
Facilitator, Pressure Vessel Projects: Dr. Richard Lee, Management and Engineering Consultants

IEEE - Institute of Electrical and Electronics Engineers

IEEE is a leading authority in technical areas ranging from computer engineering, biomedical technology and telecommunications, to electric power, aerospace and consumer electronics. IEEE develops and publishes standards in such categories as definitions and terminology; methods of measurement and tests; ratings structures, temperature limits, application guides; recommended practices; and safety.

NIST - National Institute of Standards and Technology/Information Technology Laboratory
The National Institute of Standards and Technology, a non-regulatory federal agency within the US Commerce Department, develops and promotes standards and technology. The NIST/ITL produces standards and guidelines for information exchange relating to automatic data processing and related systems.

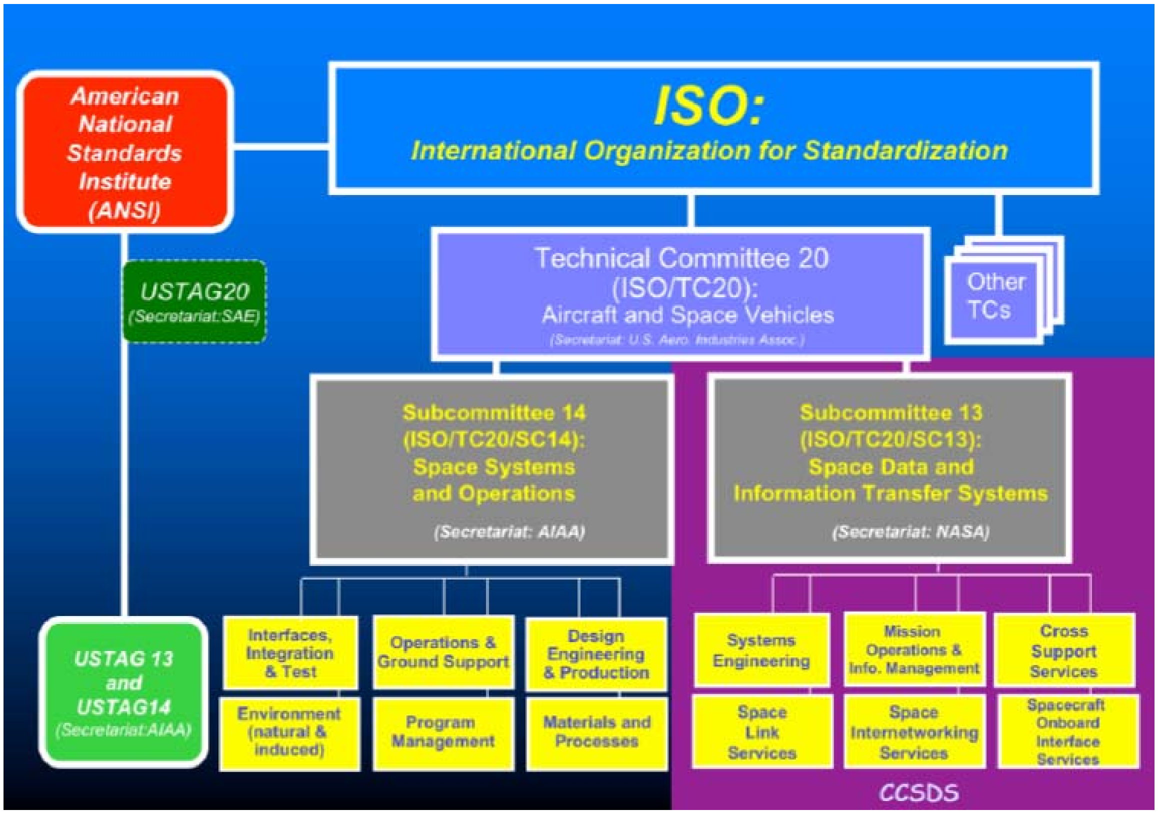
4.4 ISO Technical Committee 20 – Aircraft and Space Vehicles

Table 7 lists the working groups and subcommittees in TC 20. Due to their focus on space industry standardization, the US involvement in subcommittees 13 and 14 will be described in this report. Other subcommittees of interest may be reviewed at www.iso.org.

Table 7 ISO/TC20 Subcommittees

	Subcommittee Name	**Focus**
TC 20/SC 1	Aerospace electrical requirements	Aviation
TC 20/SC 4	Aerospace fastener systems	Aviation
TC 20/SC 6	Standard atmosphere	Aviation
TC 20/SC 8	Aerospace terminology	
TC 20/SC 9	Air cargo and ground equipment	Aviation
TC 20/SC 10	Aerospace fluid systems and components	Aviation
TC 20/SC 13	Space data and information transfer systems	Space
TC 20/SC 14	Space systems and operations	Space
TC 20/SC 15	Airframe bearings	Aviation

Figure 11 depicts the US involvement in the overall standards development process for TC20/SC13&14. ANSI is the secretariat at the ISO level for TC20. Part of ANSI's responsibilities as the US member body to the ISO includes accrediting US Technical Advisory Groups (US TAGs), whose primary purpose is to develop and transmit, via ANSI, US positions on activities and ballots of the international technical committee. There are three US Technical Advisory Groups (TAGs) that provide US



input for standards developed under TC 20.

Figure 11 US Standards Development for ISO/TC20/SC13&14

The following tables summarize the status of SC13&14 standards activities.

Table 8 ISO Space Systems and Operations Subcommittee 13 Standards

ISO 11103	Radiometric and Orbit Data	Published
ISO 11104	Time Code Formats	Published
ISO 11754	Telemetry Channel Coding	Published
ISO 12171	Telecommand Part 1 – Channel Services	Published
ISO 12172	Telecommand Part 2 – Data Routing Services	Published
ISO 12173	Telecommand Part 2.1–Command Ops Procedures	Published
ISO 12174	Telecommand Part 3–Data Management Procedures	Published
ISO 12175	SFDU – Structure and Construction Rules	Published
ISO 13419	Packet Telemetry	Published

ISO 13420	AOS, Network&Data Links: Architectural Specification	Published
ISO 13764	SFDU – Control Authority Procedures	Published
ISO 14721	Open Archival Information System - Reference Model	Published
ISO 14961	PVL Specification	Published
ISO 14962	ASCII Encoded English	Published
ISO 15395	SFDU – Control Authority Data Structures	Published
ISO 15396	Cross Support Reference Model – SLE Services	Published
ISO 15887	Lossless Data Compression	Published
ISO 15888	SFDU – Referencing Environment	Published
ISO 15889	Data Description Language – EAST Specification	Published
ISO 15891	SCPS – Network Protocol	Published
ISO 15892	SCPS – Security Protocol	Published
ISO 15893	SCPS – Transport Protocol	Published
ISO 15894	SCPS – File Protocol	Published
ISO 17355	CCSDS File Delivery Protocol	Published
ISO 17433	Packet Telemetry Services	Published
ISO 21961	Data Entity Dictionary Specification Language (DEDSL) – Abstract syntax	Published
ISO 21962	Data Entity Dictionary Specification Language (DEDSL) – PVL syntax	Published
ISO 22643	Data Entity Dictionary Specification Language (DEDSL) – XML/DTD syntax	Published
ISO/DIS 22663	Space data and information transfer systems -- Proximity-1 space link protocols	
ISO/DIS 22669	Space data and information transfer systems -- Space link extension (SLE) -- Return all frames service	
ISO/DIS 22671	Space data and information transfer systems -- Space link extension (SLE) -- Forward command link transmission unit (CLTU)	

Table 9 ISO Space Systems and Operations Subcommittee 14 Standards[24]

Status report as of 9/9/2003 — Space systems and operations — ISO/TC20/SC14 N 250

ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
Working Group #1 Design Engineering							
14302	Space systems - Electromagnetic compatibility requirements	Trout, Dawn	International Standard published	12/15/2002	International Standard under periodic review	12/15/2007	WG Experts
14304	Space systems - Explosive devices and systems	Goldstein, Selma	Comments/voting summary circulated	9/17/2002	Resolve CD comments	7/31/2003	Project Leader
14621-1	Space systems - Electrical, electronic, and electromagnetic (EEE) parts - Parts management	Ingram-Cotton, John B.	International Standard under publication	2/4/2003	International Standard published	10/30/2003	Central Secretariat
14621-2	Space systems - Electrical, electronic, and electromagnetic (EEE) parts - Control program requirements	Folco, Yves	International Standard published	7/15/2003	International Standard under periodic review	7/15/2007	WG Experts
14622	Space systems - Structural design - Loads and induced environment	Hrisafovic, N.	International Standard published	12/15/2000	International Standard under periodical review	12/15/2004	Working Group
14623	Space systems - Structural design - Pressure vessels and pressurized structures - Design and operation	Chang, James B.	FDIS ballot initiated: 2 months. Proof sent to secretariat	7/31/2003	National votes due	9/30/2003	HODs
14953	Space systems - Structural design - Determination of loading levels for a static qualification test of launch vehicles	Hrisafovic, N.	International Standard published	5/1/2000	International Standard under periodical review	5/1/2004	Working Group
14954	Space systems - Exchange of Mathematical Models for Dynamic and Static Analysis	Blanchard, Patrice	Resolve comments from DIS vote	5/6/2003	Align French and English Texts	9/30/2003	Project Leader

Status report as of 9/9/2003 Space systems and operations ISO/TC20/SC14 N 250

ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
15387	Space systems - Space Solar Cells - Measurement and Calibration Procedures	Kiyota, Yoshiharu	Modify text for FDIS	7/23/2003	Align French and English Texts	10/6/2003	French Delegation
16447	Space systems - Selection of Structural Materials for Space Vehicles	Menke, Manfred	Project deleted	12/1/2001			
16448	Space systems - Selection of production processes for space vehicles	Menke, Manfred	Project deleted	5/18/2000			
16452	Space systems - Thermal Analysis - Exchange of Mathematical Models	Fougeras, Jean	Project deleted	5/18/2001			
16454	Space systems - Structural Design - Stress Analysis Requirements	Vvedensky, Nickolay	Initiate CD/V	7/24/2003	CD/V ends	9/24/2003	HODs
16456	Space systems - Cables and Wires - Arc Tracking Test	Reher, Heinz-Joseph	Initiate CD/V	8/29/2003	CD/V ends	10/29/2003	HODs
16749	Space Systems – Calculation for Threaded Fasteners	Dacal, Rafael Bureo	New PL appointed	5/27/2003	Circulate new WD	8/15/2003	Project Leader
21347	Space systems-Structural design–Fracture and damage control for spaceflight structures	Chang, James B.	DIS registered	9/4/2003	DIS Ballot to be initiated by CenSec	10/4/2003	Central Secretariat

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
22010	Space systems – Mass properties control	MacNeil, Ian	Resolve CD comments	8/11/2003	Discuss comment resolutions within WG	10/30/2003	WG Experts
23037	Space systems - Electromagnetic interference test methods	Schueler, Holger	Working draft (WD) study initiated	10/3/2001	Reaffirm interest in project	7/1/2003	WG Experts
23038	Space systems - Space solar cells - Electron and proton irradiation test methods	Kiyota, Yoshiharu	Resolve CD comments	7/26/2003	Initiate CD/V	9/1/2003	Secretariat
23039	Space systems – Multi-junction solar cells – Measurement and calibration procedures	Baraona, Cosmo	Working draft (WD) study initiated	12/1/2001	Complete any necessary research and testing	9/1/2003	WG Experts
			Working Group #2 Interfaces				
14303	Space systems - Spacecraft to Launch Vehicle Interfaces	Boland, Philippe Mavrogenis, James	International Standard published	10/22/2002	International Standard under periodic review	10/22/2005	WG Experts
15862	Space systems - LV-SC Flight Environment Requirements for Telemetry Data Processing	Pan, Zhongwen	WD comments resolved	5/14/2003	Prepare new WD	10/4/2003	WG Experts
15863	Space systems - Spacecraft to launch vehicle interface control document	Boland, Philippe	International Standard under publication	4/30/2003	International Standard published	9/30/2003	Central Secretariat
15864	Space systems - General tests for spacecraft	Ono, Takaki	Voting summary dispatched	9/6/2003	Resolve comments from DIS vote	11/6/2003	Project Leader

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
17401	Space systems - Spacecraft interface requirements document for launch services	Boland, Philippe	Voting summary dispatched	1/19/2003	Resolve comments from DIS vote	7/19/2003	Project Leader
17566	Space systems – General test documentation	Haughton, Jim Raynor, Bill	Resolve 1st WD comments	5/14/2003	Circulate new WD	9/15/2003	Project Leader
19933	Space systems - Format for spacecraft launch environmental test report	Boland, Philippe	New project registered in TC/SC work program		Working draft (WD) study initiated	10/4/2003	Project Leader
			Working Group #3 Operations				
14619	Space systems - Space experiments - General requirements	Fomitchev, Gregori	FDIS ballot initiated: 2 months. Proof sent to secretariat	7/24/2003	National votes due	9/24/2003	HODs
14620-1	Space systems - Safety requirements - Part 1: System safety	Baccini, Henri	International Standard published	12/1/2002	International Standard under periodic review	12/1/2006	WG Experts
14620-2	Space systems - Safety requirements - Part 2: Launch site operations	Baccini, Henri	International Standard published	10/5/2000	International Standard under periodic review	10/5/2004	Working Group
14620-3	Space systems — Safety requirements — Part 3: Flight safety systems	Baccini, Henri	CD approved for registration as DIS	7/28/2003	Resolve CD comments	9/28/2003	Project Leader
14625	Space systems - Ground support equipment for use at launch, landing, or retrieval sites - General requirements	Schultz, Larry	Initiate member body review	7/16/2003	Review input due to secretariat	1/16/2004	HODs

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
14711	Space systems - Unmanned mission operations concepts – Guidelines	Durham, David	International Standard published	3/1/2003	International Standard under periodic review	3/1/2007	WG Experts
14721	Space systems - Archiving space data		Project deleted	10/1/1994			
14950	Space systems - Unmanned spacecraft operability		FDIS registered for formal approval	5/20/2003	FDIS ballot to be initiated by Central Secretariat	9/20/2003	Central Secretariat
14951-1	Space systems - Fluid characteristics - Part 1: Oxygen propellant	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-10	Space systems - Fluid characteristics - Part 10: Water	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-11	Space systems - Fluid characteristics - Part 11: Ammonia	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-12	Space systems - Fluid characteristics - Part 12: Carbon Dioxide	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-13	Space systems - Fluid characteristics - Part 13: Breathing air	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
14951-2	Space systems - Fluid characteristics - Part 2: Hydrogen propellant	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-3	Space systems - Fluid characteristics - Part 3: Nitrogen	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-4	Space systems - Fluid characteristics - Part 4: Helium	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-5	Space systems - Fluid characteristics - Part 5: Nitrogen tetroxide propellant	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-6	Space systems - Fluid characteristics - Part 6: Monomethylhydrazine propellant	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-7	Space systems - Fluid characteristics - Part 7: Hydrazine propellant	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-8	Space systems - Fluid characteristics - Part 8: Kerosene propellant	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group
14951-9	Space systems - Fluid characteristics - Part 9: Argon	Schultz, Larry	International Standard published	9/30/1999	International Standard under periodic review	9/30/2003	Working Group

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
14952-1	Space systems - Surface cleanliness of fluid systems - Part 1: Vocabulary	Bryan, Coleman	FDIS ballot initiated: 2 months. Proof sent to secretariat	8/15/2003	National votes due	10/14/2003	HODs
14952-2	Space systems - Surface cleanliness of fluid systems - Part 2: Cleanliness levels	Bryan, Coleman	FDIS ballot initiated: 2 months. Proof sent to secretariat	8/15/2003	National votes due	10/14/2003	HODs
14952-3	Space systems - Surface cleanliness of fluid systems - Part 3: Analytical procedures for the determination of non volatile residues and particulate	Bryan, Coleman	FDIS ballot initiated: 2 months. Proof sent to secretariat	8/15/2003	National votes due	10/14/2003	HODs
14952-4	Space systems - Surface cleanliness of fluid systems - Part 4: rough cleaning processes	Bryan, Coleman	FDIS ballot initiated: 2 months. Proof sent to secretariat	8/15/2003	National votes due	10/14/2003	HODs
14952-5	Space systems - Surface cleanliness of fluid systems - Part 5: Processes for drying eqiupment	Bryan, Coleman	FDIS ballot initiated: 2 months. Proof sent to secretariat	8/15/2003	National votes due	10/14/2003	HODs
14952-6	Space systems - Surface cleanliness of fluid systems - Part 6: Precision cleaning processes	Bryan, Coleman	FDIS ballot initiated: 2 months. Proof sent to secretariat	8/15/2003	National votes due	10/14/2003	HODs
15389	Space systems - Flight to ground umbilicals	Schultz, Larry	International Standard published	2/25/2000	International Standard under periodic review	2/25/2004	Working Group
15389 DAM 1	Space systems – Flight to ground umbilicals – Amendment 1: Add Annex A, Prevention of accidental cross connection	Tsukanov, Evgeny	Initiate CD/V	7/8/2003	CD/V ends	10/8/2003	HODs

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
15859-1	Space systems - Fluid Sampling and Test Methods - Part 1: Oxygen	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-10	Space systems - Fluid sampling and test methods - Part 10: Water	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-11	Space systems - Fluid sampling and test methods - Part 11: Ammonia	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-12	Space systems - Fluid sampling and test methods - Part 12: Carbon dioxide	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-13	Space systems - Fluid sampling and test methods - Part 13: Breathing air	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-2	Space systems - Fluid Sampling and Test Methods - Part 2: Hydrogen propellant	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-3	Space systems - Fluid sampling and test methods - Part 3: Nitrogen	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-4	Space systems - Fluid sampling and test methods - Part 4: Helium propellant	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
15859-5	Space systems - Fluid sampling and test methods - Part 5: Nitrogen tetroxide propellant	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-6	Space systems - Fluid sampling and test methods - Part 6: Monomethylhydrazine propellant	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-7	Space systems - Fluid sampling and test methods - Part 7: Hydrazine propellant	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-8	Space systems - Fluid sampling and test methods - Part 8: Kerosene propellant	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15859-9	Space systems - Fluid sampling and test methods - Part 9: Argon	Schultz, Larry	FDIS registered for formal approval	7/7/2003	FDIS ballot to be initiated by Central Secretariat	10/7/2003	Central Secretariat
15860	Space systems - Gas contamination - Field Measuring Methods	Tsukanov, Evgeny	Re-register DIS at central secretariat	9/6/2003	DIS Ballot to be initiated by CenSec	10/6/2003	Central Secretariat
15861	Space systems - Mobile Space Exploration Robots - Design Elements	Moskowitz, Samuel	Project deleted	7/1/1998			
16091	Space systems - Integrated Logistic Support	Menke, Manfred	International Standard published	12/1/2002	International Standard under periodic review	12/1/2006	WG Experts

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
16458	Space systems - Unmanned Spacecraft Transportation	Osipov, Sergei	FDIS ballot initiated: 2 months. Proof sent to secretariat	9/18/2003	National votes due	11/18/2003	HODs
17399	Space systems – Man-systems integration	Schultz, Larry	DIS approved for publication	5/16/2002	International Standard under publication	12/15/2002	Central Secretariat
17400	Space systems-Launch and integration site general test requirements	Tsukanov, Evgeny	TR published	2/15/2003			
22108	Space systems - Non-flight items in flight hardware - Identification and control	Hobbs, Steven	Comments/voting summary circulated	5/16/2002	Resolve CD comments	1/1/2003	Project Leader
23041	Space systems – Unmanned spacecraft operational procedures – Documentation	Miyashita, Makoto	WD comments due to PL	6/1/2003	WD approved for registration as CD	10/31/2003	WG Experts
Working Group #4 Space Environments							
15390	Space systems - Models of galactic cosmic rays	Nymmik, Rikho	Submit text to Cen Sec for publication	9/7/2003	International Standard under publication	9/22/2003	Central Secretariat
15391	Space systems - Probabilistic model of particle fluences and peak fluxes in solar cosmic rays	Nymmik, Rikho	Project changed to Technical Specification	5/16/2002	Circulate DTS for comment	10/15/2003	Project Leader
15392	Space systems - Density of the Upper Atmosphere for Altitudes below 2000 km	Rees, David Zaitsev, Evgeny	Project changed to Technical Specification	5/16/2002	Circulate DTS for comment	10/15/2003	Project Leader

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
15856	Space systems - Space environment - Simulation guidelines for radiation exposure of non-metallic materials	Borson, Eugene N. Briskman, Boris	WD comments resolved	10/9/2002	WD approved for registration as CD	9/9/2003	Working Group
15857	Space systems - Method for Estimation of Future Solar and Geomagnetic Activity Used in Determining Earth Orbital Altitude Density	Shevirev, Alexander Thompson, Richard	Project changed to Technical Specification	5/16/2002	New PL appointed	9/9/2003	Working Group
16457	Space systems - Earth's Ionosphere and Plasmasphere	Bilitza, Dieter Gulyaeva, Tamara	Project changed to Technical Specification	5/16/2002	Circulate DTS for comment	9/9/2003	Project Leader
21348	Space systems – Space environments – Solar irradiance determinations	Nusinov, Anatoliy Tobiska, Kent	CD/C ends	11/4/2002	Resolve CD comments	2/20/2003	Project Leader
22009	Space systems - Model of Earth's magnetospheric magnetic field	Alexeev, Igor	WD approved for registration as CD	5/15/2003	Committee draft (CD) registered	8/15/2003	Project Leader
			Working Group #5 Program Management				
14300-1	Space systems - Program management	Borycki, Gerard	International Standard published	5/15/2001	International Standard under periodic review	5/15/2005	Working Group
14300-2	Space systems - Product assurance - policy and principles	Marcoux, Jacques	International Standard published	7/1/2002	International Standard under periodic review	7/1/2005	WG Experts
15865	Space systems - Qualification assessment	Nikoulitchev, Valery	FDIS registered for formal approval	7/24/2003	Modify text per CS	10/20/2003	Project Leader

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
16192	Space systems – Lessons learned – Principles and rules	Desroches, Alain	WD comments resolved	5/15/2003	WD approved for registration as CD	10/24/2003	WG Experts
16193	Space Systems-Probabilistic Risk Assessment (PRA)	Stamatelatos , Michael	New project registered in TC/SC work program	8/30/2002	Reaffirm interest in project	8/15/2003	U.S. Delegation
17666	Space systems - Program Management - Risk Management	Deak, Thomas Rutledge, Peter	International Standard published	4/1/2003	International Standard under periodic review	4/1/2007	WG Experts
21349	Space systems - Project reviews	Widmann, E. Richard	Resolve CD comments	5/15/2003	Initiate CD/V	7/15/2003	Project Leader
21350	Space systems - Use of off-the-shelf items in new flight applications	Widmann, E. Richard	WD comments resolved	5/15/2003	Committee draft (CD) registered	7/15/2003	Project Leader
21351	Space systems - Functional and technical specifications	Chevallier, Jean	National Votes Due	3/24/2003	Voting summary dispatched	6/24/2003	CEN Lead
Working Group #6 Materials and Processes							
14624-1	Space systems - Safety and compatibility of materials - Part 1: Test method for upward flammability of materials	Davis, Eddie	International Standard published	6/1/2003	International Standard under periodic review	6/1/2006	WG Experts
14624-2	Space systems - Safety and compatibility of materials - Part 2: Test method for electrical wires and accessories	Davis, Eddie	International Standard published	6/1/2003	International Standard under periodic review	6/1/2006	Central Secretariat

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
14624-3	Space systems - Safety and compaibility of materials - Part 3: Test method for off-gassed products from materials and assembled articles	Whitfield, Steve	DIS registered	7/9/2003	DIS Ballot to be initiated by CenSec	10/9/2003	Central Secretariat
14624-4	Space systems - Safety and compatibility of materials - Part 4: Test method for flammability of materials in gaseous oxygen	Davis, Eddie	International Standard published	6/1/2003	International Standard under periodic review	6/1/2006	WG Experts
14624-5	Space systems - Safety and material compatibility - Part 5: Test method for determination of the reactivity of materials with aerospace hypergolic propellants	Bryan, Coleman	DIS ballot initiated: 5 months	7/22/2003	National Votes Due	12/22/2003	HODs
14624-6	Space systems - Safety and material compatibility - Part 6: Test method for determining the reactivity of processing materials with aerospace fluids	Bryan, Coleman	DIS ballot initiated: 5 months	7/22/2003	National Votes Due	12/22/2003	HODs
14624-7	Space systems - Safety and compatibility of materials - Part 7: Test method for determining the permeability and penetration of materials to aerospace fluids	Bryan, Coleman	DIS ballot initiated: 5 months	7/22/2003	National Votes Due	12/22/2003	HODs
15388	Space systems - Contamination and cleanliness control	Harui, Shoichi	Resolve comments from DIS vote	2/2/2003	Align French and English Texts	8/1/2003	WG Experts
16455	Space systems - Design Criteria for Controlling Stress Corrosion Cracking	Torres, Pablo	New project ballot initiated	7/9/2003	Project reaffirmed by plenary	10/9/2003	HODs
20232	Space systems – Characterisation of a new composite material	Turzo, Guy	New project registered in TC/SC work program	7/24/2003	Working draft (WD) study initiated	10/10/2003	Project Leader

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ISO #	Title	Project Lead(s)	Last Action Completed	Last Action Date	Next Applicable Action	Due Date	Responsible Party
22538-1	Space Systems – Oxygen Safety – Part 1: Hazards analysis for oxygen components and systems	Bryan, Coleman	DIS ballot initiated: 5 months	7/16/2003	National Votes Due	12/14/2003	HODs
22538-2	Space Systems – Oxygen Safety – Part 2: Selection of metallic materials for oxygen components and systems	Bryan, Coleman	DIS ballot initiated: 5 months	7/14/2003	National Votes Due	12/14/2003	HODs
22538-3	Space Systems – Oxygen Safety – Part 3: Selection of non-metallic materials for oxygen components and systems	Bryan, Coleman	DIS ballot initiated: 5 months	7/14/2003	National Votes Due	12/14/2003	HODs
22538-4	Space Systems – Oxygen Safety – Part 4: Design of oxygen components and systems	Bryan, Coleman	DIS ballot initiated: 5 months	7/14/2003	National Votes Due	12/14/2003	HODs
22538-5	Space systems — Oxygen safety — Part 5: Operational and emergency procedures	Bryan, Coleman	Circulate new WD	4/21/2003	WD comments due to PL	8/14/2003	WG Experts
22538-6	Space systems — Oxygen safety — Part 6: Facility planning and implementation	Bryan, Coleman	Circulate new WD	4/21/2003	WD comments due to PL	8/14/2003	WG Experts

Total Number of Projects: 110

4.4.1 Summary

As Table 8 and Table 9 illustrate, different subcommittees within a TC will vary on their production of standards. Although SC 13 and 14 were formed at approximately the same time, SC 14 has progressed much more rapidly. Due to the nature of SC 14 activities (i.e. operations), RTI recommends that ASTWG invite representatives from TAG 14 to future ASTWG workshops. Additionally, RTI feels that representatives from the ASTWG Technology Team need to take part in future standards-making activities in both TAG 13 & 14.

5 Other Considerations

To obtain greater participation in ASTWG from technology experts, RTI suggests inviting representatives from the following organizations to participate in ASTWG meetings:

- JANNAF (Joint Army NASA Navy Air Force) Interagency Propulsion Committee and Propellant Development and Characterization Subcommittee
- AIAA (American Institute of Aeronautics and Astronautics) – Several Committees on Standards
- CPIA (Chemical Propulsion Information Agency).
- FAA Commercial Space Transportation Advisory Committee (COMSTAC) Launch Operations and Support Working Group
- National Hydrogen Association
- DOE (Clean Car, Clean Fuel)
- Florida Hydrogen Partnership
- American Society for Nondestructive Testing

This list is not meant to be all encompassing. It is simply intended to plant the seed for developing relationships between focused technology groups and the ASTWG.

6 References

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David Montana, BBN Technologies; 10 Moulton Street, Cambridge, MA 02138, <dmontana@bbn.com>

ASCENT Technology, Inc. July 29, 2003. <http:// www.smartairport.com/sap>

Data Mining and Knowledge Discovery Approach for Optimizing Critical Operations Project; A Mass Optimization Effort; Design and Development of a New Telecommunications Information Management System. Ed. Amar Gupta. Massachusetts Institute of Technology. < http://web.mit.edu/ctl/www/research/research02-03 >

http://www.fm-webview.com/webview/schedules.html

http://www.niso.org/international/about_intl.html#howint

http://www.ece.utexas.edu/

http://www.inovanetworks.com/

Appendix A - Research Notes

The following matrix highlights the regulations, technologies, procedures, and best practices employed by various hypergol users.

ASTWG Advanced Servicing: Hypergolic Propellants Benchmarking Matrix						
Technology	Handler	Regulations/Technologies/Procedures/Best Practices Employed in Parallel Industries				
		Transportation	Storage	Transfer	Personnel Protective Equipment (PPE)	Disposal
Propellant Grade (99% pure)	NASA and contractors (United Paradyne Corp, Caltech)	• KSC developed standards for tanker trucks have been adopted by the DOT • Same standards now used by the DoD, Arch Chemicals, and other organizations	• KSC currently uses tanker trucks and 4BW cylinders for storage • KSC is moving to develop bulk on-site storage	• Follows NASA safety procedures • Unique application for man rated system and large quantities of hypergols • Loading via manual servicing carts	• SCAPE suits and dosimeter badges are used for all operations	• Limited on-site waste disposal via UV Rayox system and wastewater treatment • Most waste trucked to offsite commercial incinerator • Some recycling done when mixed with water only
	DoD	• Uses standard 30 or 55 gallon drums or same assets used by DoD or NASA • VAFB uses rail tank cars for delivery • Aircraft transport is not yet allowed	• Weapons are stored "wet" (fueled and ready to deploy) for decades • Some bulk on-site storage at Titan (Cape Canaveral) launch pad facility • VAFB has bulk on-site storage.	• Typically lower quantities of hypergols than NASA loaded into unmanned systems where leaks are not of great concern • Some loading directly (no servicing cart).	• Cartridge type respirator, face shield, and gloves are used in most operations • No dosimeter badges • VAFB uses SCAPE suits	• Similar to NASA

	Commercial (e.g., Boeing, LMCO, Hamilton Sundstrand, Aerojet, Arch Chemical)	• Uses standard 30 or 55 gallon drums or same assets used by DoD or NASA	• Arch Chemical has sole bulk storage facility near Mobile, Alabama • Aerojet bulk storage facility is mothballed • Others use standard drums or facilities of DoD or NASA • Dams and drains ensure any spill is captured in the hazardous waste sump • Mixed feedback was received on the need for improved sensor technology	• LMCO automated remote loading system at VAFB • Automated leading cart developed by LMCO was not viable • Boeing and LMCO has eliminated intermediate cart tank • Process water is continuously run to allow spills to be quickly rinsed • Pumping is direct from the storage drum into the fuel tank with no servicing cart, with the head being supplied by low-pressure nitrogen.	• Plant air is constantly monitored • When hydrazines are under significant pressure, the area is locked, safety lights are on, and personnel are not allowed in the area • One entity reported using dosimeter badges, which may not be specific to hydrazines, issued on a periodic (quarterly) basis • Use lower cost disposable or Class B chemical suits when suits are necessary • When pumping hydrazines or performing other operations involving open hydrazines, operators wear respirator, face shield, gloves, and rubber smock	• Afterburners installed in exhaust system for tests ensure no hazardous waste is released into the environment • Solvent waste from cleaning and water waste from loading operations is trucked away by a hazardous waste contractor • Large quantities of hydrazine waste, once certified, can benefit the anaerobic sewerage process and is disposed into the sewer system • At production facility, manufacturer recycle some back into the process

Solutions Grade (64%, 51%, 35%)	Power Plants, Foam Manufacturers, Chemical Producers	• These chemicals are classified differently from their propellant-grade cousins and are subject to different procedures • The solution water reduces the vapor pressure of the toxic component, reduces reactivity, eliminates the combustion concern	• Drums of reducers are stored away from oxidants • Drums are retuned and refilled	• Generally users prove their operation does not cause significant exposure, then repeat the same procedures in every operation such that substantial personnel protection is not required	• SCAPE suits are never used unless a worker is known to be in contact with the chemical • Dosimeter badges not regularly used • Although seldom used, sensors were reported to be adequate	• Chemical is generally consumed in the process

Matrix

The following matrix highlights the regulations, technologies, procedures, and best practices employed by various cryogenic fluid users.
Advanced Servicing Need:
Cryogenic Fluids (LOx, LH_2, etc.)
Benchmarking Matrix

Technology	Handler	Regulations/Technologies/Procedures/Best Practices Employed in Parallel Industries			
		Transportation	Storage	Transfer	Disposal
Propellant Grade (low purity required)	NASA, commercial launch operators (e.g., LMCO, Boeing), DoD	• DOT has established common regulations for cryo transport used by all applications • KSC deliveries generally via 13,000 gallon tanker truck from New Orleans area • NASA requires capacity for 30 tankers/day • Rail service has been tried but was too slow • Commercial launch companies purchase via DESC and directly from vendors • Commercial launch supply of 3-5 trailers per day is for lower price than NASA due to more economic logistics pattern • DoD and NASA material is ordered to MIL specifications, but NASA slowly moving	• KSC uses four 1960s era 800,000 gallon dewar spheres kept filled at all times (due to age) requiring a 30 tanker/day surge in delivery after a launch • KSC considering on-site production system similar to existing GN2 pipeline • KSC uses both gas sensors and flame detectors • In partnership with others, LMCO developed densified cryogenic technology as part of X-33 but not yet used in operations • VAFB launch rate lower than that of KSC/CCAFS; therefore, cryogenic propellant tanks generally not kept filled at all times	• Transfer from tanker truck to storage tank for KSC monitored by fire truck and team of safety people • Special purging and connection processes developed over 50 years are now standard across the cryogenic industry • Handlers wear Nomex suits • Transfer from KSC's spherical storage tank to vehicle is via precooled long 1960s era vacuum jacketed pipe which introduces significant losses • NASA considering liquefaction at the launch pad • No common interface or requirements exist today that might enable the ASTWG vision	• Boil off of 600 gallons/day per KSC spherical storage tank is vented or burned via flare stack • KSC is considering powering a fuel cell with the boil off or reliquifying

		to lower cost commercial specifications • No supply consolidation among current spaceport users • KSC does consolidate all supply for other NASA field centers			
Process Grade	Electronics, Petrochemical	• DOT regulations and transportation same as for propellant applications • Higher purity (ppb range) required for electronics than for propellant applications requires product be connected to analyzer longer	• Some tanks are super insulated (Mylar and aluminum foil with hard vacuum), whereas others are lower-cost soft vacuum and perlite insulated • Note that 95% of the hydrogen market today is for gaseous hydrogen, some of which is piped from gas supplier plant into petroleum refiners' facilities in California, Texas, and Louisiana	• Transfer from truck to storage tank done by truck driver alone • Pumping is via electrical pump or gas pressure	

Fuel Cell Grade	Automotive, Power Generation	• Hydrogen will be provided by tanker truck or, more likely, by reforming natural gas at or near fueling station • Energy companies (e.g., Exxon Mobil, Shell, BP) plan to take over commodity business	• Fueling stations are now being designed • Vehicles use high pressure gas, metal hydride, or cryogenic storage; however, it appears that high pressure (~10 ksi) gaseous hydrogen will be the fuel of choice for a vast majority of applications • Building codes for structures which may encounter hydrogen are now being developed • Leveraging sensing technologies originally developed for NASA launch operations • Gas sensors are favored over flame detectors due to false alarm rate	• Standard, safe fueling nozzles similar in operation to gasoline dispensers now being designed • Technical hurdle in heat of compression of gaseous hydrogen preventing a 100% fill is being addressed through temperature feedback • Grounding may be ensured through more conductive future tires as well as operations that require the user to ground themselves prior to a transfer	

Matrix

The following matrix highlights the regulations, technologies, procedures, and best practices employed by various solid propellant handlers.
Advanced Servicing Need:
Solid propellants
Benchmarking Matrix

Technology	Handler	Regulations/Technologies/Procedures/Best Practices Employed in Parallel Industries			
		Transportation	Storage	Transfer	Disposal
Solid propellants	NASA and on-site contractors	• Solid rocket boosters are transported in one piece -- protection from mechanical shocks or abrupt temperature changes is key to prevent cracks in the material grain	• Facilities having fire walls, fire protection systems, operational shields, substantial dividing walls, blast resistant roofs, containment structures, and earth covered magazines • Electrostatic discharge controls such as conductive floor tile and legstats or conductive work shoes • Lightning protection with resistance of 25 ohms or less to ground; metallic surfaces containing explosives must be bonded and grounded • Building, magazines, and containers must have the appropriate safety markings • Solid propellants are not to be stored with initiating explosives, detonators, explosive devices with detonators, or	• Due to the nature of solid propellants, mixture of the propellant chemical is done in manufacturing facility. Transfer after the component (e.g., solid rocket) is assembled then becomes a transportation issue until final use.	• The Solid Rocket Booster (SRB) recovery operation at KSC's Hangar AF renovates the SRBs from space shuttle launches and prepares them for reuse. Cleaning of the SRB tubes generates two waste streams on a "per launch" cycle basis.

			ammunition		
	DoD		• Solid propellants offer the advantage of minimum maintenance and instant readiness. However, the more energetic solids may require carefully controlled storage conditions, and may offer handling problems in the very large sizes, because the rocket must always be carried about fully loaded. Protection from mechanical shocks or abrupt temperature changes that may crack the grain is essential.		• Several sites that historically handled ammonium perchlorate are now EPA superfund sites.
	Commercial (e.g., Boeing, LMCO, munitions mfg.)	• AP is stable in pure form at ordinary temperature. • AP is a fire or explosive risk if contaminated with fuels, organic material, powdered metals, or reducing agent. • AP can be classified as an oxidizer or high explosive.			
	Manufacturer (Western Electrochemical, Alcoa)	• Bulk aluminum transported in sealed drums, no monitoring technology used	• AP originally in table salt form – when processed more like gray (pencil) eraser material.		• If collected correctly AP can be recycled and reused in other propellants, munitions, or explosives

Matrix

The following matrix highlights the regulations, technologies, procedures, and best practices employed by various petroleum fluid users.

Advanced Servicing Need:
Petroleum propellants
Benchmarking Matrix

Technology	Handler	Regulations/Technologies/Procedures/Best Practices Employed in Parallel Industries			
		Transportation	Storage	Transfer	Disposal
Petroleum propellants	NASA and on-site contractors	• KSC typical – 7200 gallon petrosteel tanker (see attachments)	• Available in fixed storage containers and tankers (see attachments)	• Kerosene is a relatively low maintenance fuel that allows for easier ground handling and decreased operational costs. In addition, because it is not a cryogenic, or extremely cold, fuel like hydrogen, the propulsion system does not require insulation for propulsion-related ducts, valves, lines and actuators -- saving weight and cost.	
	DoD				
	Commercial (e.g., Boeing, LMCO)	• Potential legislation may require tracking technology in trucks and HAZMAT "flight plans" that detail each delivery plan and monitors	• Leak detection and self diagnostics are playing a larger role, due to environmental concerns	• Industry focus is shifting from leak detection to inventory management and delivery forecasting	• Soil and water pollution due to permeation of fuels through hoses is of concern.

	Manufacturers	any deviations. Key technologies include GPS and central database tracking system.			• Waste must meet all applicable local, state, and federal regulations. Empty containers returned to supplier or drum reconditioner.

The following table indicates some of the alternative approaches employed by the various industries that were researched:

ASTWG Roadmapping
Dynamic Scheduling Technology
RTI Data Collection Sheet

ASTWG Dynamic scheduling Need (i.e. what needs scheduling/tracking)	Attributes of Interest	"Other Industries"	Regulations/Technologies/Procedures/Best Practices Employed in other industries			
						General Comments
People	Work Plan Status of Work in Progress Status of Person Future schedule of person	Aviation Medical	Automated tools were identified in the flight crew management area. For example, data relative to flight crew times are aggregated, to ensure that mandatory crew rest is met.[25] Additionally, the crew is able to access/update their schedule inputs and assignment information (e.g. hotel reservations) over the web. Flight information is automatically updated via link to Volpe center Medical field uses relational database technology to manage employee credentialing information, employee availability, etc; however, data input and schedule composition is manual.[26]			Data of interest • Status/Availability • Planned Activity • Capability • Weight / priority Note: this directly mitigates risk associated with crew fatigue
Facilities	Status of Facility (who is using it and for how long is it planned) Plan and Status of future users	Aviation	No true aviation "facility" <u>scheduler</u> was identified. There is significant work relative to databasing of resource information (e.g. size, location, and capacity information for operational planning) Many universities use automated schedulers that			Of interest: Manage all pricing and billing including rates, calculations, invoicing, payments and accounts receivable. Automatic conflict resolution

		Universities Medical (surgery, hospital beds, …)	are web based to dynamically schedule and deconflict facilities (laboratories, classrooms, etc.)[27,28] ; however, these schedulers are stand alone systems only (i.e. they are not integrated with other resources). They do, however, track costs and perform automatic conflict detection/resolution. Within the medical community, there is more emphasis on database – human in the loop data management of facility schedules.	Define any number of facilities and their characteristics (including maintenance/repair status)
Instrumentation/GSE	Capability Status Future schedule	Telecommunication	Within the Air Force, scheduling of a worldwide network of limited resources to meet diverse mission needs (e.g., scheduling time on the antennas comprising the Air Force Satellite Control Network) is currently accomplished manually, using a very time consuming and personnel-intensive method. However, within the operations centers, the ACE Visual Scheduler[29] enabled the Center for Research Support (CERES) to instantaneously prioritize and deconflict their local communication resources and assign each scheduled contact to an operational string.	
Vehicles/Payload (i.e. users)	Status/State of Health Processes Schedule	Aviation	Within aviation, engine manufacturers have installed sensors and on-board computers that monitor engine performance and provide fault diagnostics during flight. This information is stored on-board and may also be sent to the factory for detailed analysis. Wireless downlink of data from the plane occurs intermittently due to bandwidth and cost considerations. They do employ automated trend analysis tools, however, there does not appear to be any automated link between this data and any maintenance schedules.	

Appendix B - Technology Correlations To Hypergol Technology

H1				• Enhanced hypergolic sensing technologies:
	C1			- On-chip nanosensors
	C1	S1,S2		- Distributed sensor networks
				- Standard wireless encrypted data links from vehicle to ground hypergol systems
	C1	S1,S3	P2	- Noninvasive sensing of temperature, pressure, flow rate, and other factors to enable feedback on operations without introducing the possibility of leaks
	C1			- Improved response time, accuracy, sensitivity, and maintainability
			P2	- Centralized monitoring systems for leak or concentration detection
H2				• Optimization of hypergolic fueling carts:
				- Elimination of intermediate fueling tank
			P1	- Automation through development of standards for interfaces
H3				• Improved hypergolic storage technology:
			P1	- Development of pre-filled hypergol tanks to enable modular replacement
	C2	S3	P1	- Automated and/or remote loading operations to eliminate fueling carts
	C5			- Simplified low cost manufacturing for on-site, on-demand production of hypergols
H4				• Optimized hypergolic propellant handling plans, procedures, engineering controls, and PPE:
				- Protective clothing comfortable for outdoor use in accordance with levels of potential exposure
				- Emergency showers, breathing apparatus, and other PPE ready for immediate standby use in hypergolic fueling areas
				- Integral ground systems for containing and mitigating spills
	C2		P1,P4	- Leak-proof quick connect fittings with redundant seal paths
			P1	- Machine vision for automated alignment and mating of umbilical
	C2, C3, C5, C6, C8	S3	P1,P2	- Smart umbilicals that provide automatic process verification for issues such as connection, continuity, flow rate, and leak tightness that are capable of taking corrective action if acceptable conditions are not met
				- Integral static electricity grounding systems
H5		S5	P3	• Optimized hypergolic system cleaning and decontamination (e.g., ion exchange resins) such that most waste can be accepted by on-site sewage system or

				waste can be accepted by on-site sewage system or recycled back into process
H6	C2, C3		P2	• Hypergolic storage containers with:
				- Integrated temperature control
				- Integral pumping and shield gas systems
H7	C1, C2		P1, P2, P3	• Standardization of on-board hypergolic tanks such that operations are common, routine, and repeatable

Appendix C - ISO Technical Committee List

ISO Technical Committees	
JTC 1	Information technology
TC 1	Screw threads - STAND BY
TC 2	Fasteners
TC 4	Rolling bearings
TC 5	Ferrous metal pipes and metallic fittings
TC 6	Paper, board and pulps
TC 8	Ships and marine technology
TC 10	Technical product documentation
TC 11	Boilers and pressure vessels
TC 12	Quantities, units, symbols, conversion factors
TC 14	Shafts for machinery and accessories
TC 17	Steel
TC 18	Zinc and zinc alloys
TC 19	Preferred numbers - STAND BY
TC 20	Aircraft and space vehicles
TC 21	Equipment for fire protection and fire fighting
TC 22	Road vehicles
TC 23	Tractors and machinery for agriculture and forestry
TC 24	Sieves, sieving and other sizing methods
TC 25	Cast iron and pig iron
TC 26	Copper and copper alloys
TC 27	Solid mineral fuels
TC 28	Petroleum products and lubricants
TC 29	Small tools
TC 30	Measurement of fluid flow in closed conduits
TC 31	Tires, rims and valves
TC 33	Refractories
TC 34	Food products
TC 35	Paints and varnishes
TC 36	Cinematography
TC 37	Terminology and other language resources
TC 38	Textiles
TC 39	Machine tools
TC 41	Pulleys and belts (including veebelts)
TC 42	Photography
TC 43	Acoustics
TC 44	Welding and allied processes
TC 45	Rubber and rubber products
TC 46	Information and documentation
TC 47	Chemistry

TC 48	Laboratory glassware and related apparatus
TC 51	Pallets for unit load method of materials handling
TC 52	Light gauge metal containers
TC 54	Essential oils
TC 58	Gas cylinders
TC 59	Building construction
TC 60	Gears
TC 61	Plastics
TC 63	Glass containers
TC 67	Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries
TC 68	Banking, securities and other financial services
TC 69	Applications of statistical methods
TC 70	Internal combustion engines
TC 71	Concrete, reinforced concrete and pre-stressed concrete
TC 72	Textile machinery and machinery for dry-cleaning and industrial laundering
TC 74	Cement and lime
TC 76	Transfusion, infusion and injection equipment for medical and pharmaceutical use
TC 77	Products in fibre reinforced cement
TC 79	Light metals and their alloys
TC 81	Common names for pesticides and other agrochemicals
TC 82	Mining - STAND BY
TC 83	Sports and recreational equipment
TC 84	Devices for administration of medicinal products and intravascular catheters
TC 85	Nuclear energy
TC 86	Refrigeration and air-conditioning
TC 87	Cork
TC 89	Wood-based panels
TC 91	Surface active agents
TC 92	Fire safety
TC 93	Starch (including derivatives and by-products)
TC 94	Personal safety -- Protective clothing and equipment
TC 96	Cranes
TC 98	Bases for design of structures
TC 100	Chains and chain wheels for power transmission and conveyors
TC 101	Continuous mechanical handling equipment
TC 102	Iron ore and direct reduced iron
TC 104	Freight containers
TC 105	Steel wire ropes
TC 106	Dentistry

TC 107	Metallic and other inorganic coatings
TC 108	Mechanical vibration and shock
TC 109	Oil and gas burners and associated equipment
TC 110	Industrial trucks
TC 111	Round steel link chains, chain slings, components and accessories
TC 112	Vacuum technology
TC 113	Hydrometry
TC 114	Horology
TC 115	Pumps
TC 116	Space heating appliances
TC 117	Industrial fans
TC 118	Compressors, pneumatic tools and pneumatic machines
TC 119	Powder metallurgy
TC 120	Leather
TC 121	Anesthetic and respiratory equipment
TC 122	Packaging
TC 123	Plain bearings
TC 126	Tobacco and tobacco products
TC 127	Earth-moving machinery
TC 128	Glass plant, pipeline and fittings - STAND BY
TC 129	Aluminum ores - STAND BY
TC 130	Graphic technology
TC 131	Fluid power systems
TC 132	Ferroalloys
TC 133	Sizing systems and designations for clothes - STAND BY
TC 134	Fertilizers and soil conditioners - STAND BY
TC 135	Non-destructive testing
TC 136	Furniture
TC 137	Sizing system, designations and marking for boots and shoes - STAND BY
TC 138	Plastics pipes, fittings and valves for the transport of fluids
TC 142	Cleaning equipment for air and other gases - STAND BY
TC 144	Air distribution and air diffusion - STAND BY
TC 145	Graphical symbols
TC 146	Air quality
TC 147	Water quality
TC 148	Sewing machines
TC 149	Cycles
TC 150	Implants for surgery
TC 152	Gypsum, gypsum plasters and gypsum products - STAND BY
TC 153	Valves
TC 154	Processes, data elements and documents in commerce, industry and administration

TC 155	Nickel and nickel alloys
TC 156	Corrosion of metals and alloys
TC 157	Mechanical contraceptives
TC 158	Analysis of gases
TC 159	Ergonomics
TC 160	Glass in building
TC 161	Control and protective devices for gas and oil burners and gas and oil burning appliances
TC 162	Doors and windows
TC 163	Thermal performance and energy use in the built environment
TC 164	Mechanical testing of metals
TC 165	Timber structures
TC 166	Ceramic ware, glassware and glass ceramic ware in contact with food
TC 167	Steel and aluminum structures
TC 168	Prosthetics and orthotics
TC 170	Surgical instruments
TC 171	Document management applications
TC 172	Optics and photonics
TC 173	Technical systems and aids for disabled or handicapped persons
TC 174	Jewelry
TC 175	Fluorspar
TC 176	Quality management and quality assurance
TC 177	Caravans
TC 178	Lifts, escalators, passenger conveyors
TC 179	Masonry - STAND BY
TC 180	Solar energy
TC 181	Safety of toys
TC 182	Geotechnics
TC 183	Copper, lead, zinc and nickel ores and concentrates
TC 184	Industrial automation systems and integration
TC 185	Safety devices for protection against excessive pressure
TC 186	Cutlery and table and decorative metal hollow-ware
TC 188	Small craft
TC 189	Ceramic tile
TC 190	Soil quality
TC 191	Animal (mammal) traps - STAND BY
TC 192	Gas turbines
TC 193	Natural gas
TC 194	Biological evaluation of medical devices
TC 195	Building construction machinery and equipment
TC 196	Natural stone - STAND BY
TC 197	Hydrogen technologies

TC 198	Sterilization of health care products
TC 199	Safety of machinery
TC 201	Surface chemical analysis
TC 202	Microbeam analysis
TC 203	Technical energy systems
TC 204	Intelligent transport systems
TC 205	Building environment design
TC 206	Fine ceramics
TC 207	Environmental management
TC 208	Thermal turbines for industrial application (steam turbines, gas expansion turbines) - STAND BY
TC 209	Cleanrooms and associated controlled environments
TC 210	Quality management and corresponding general aspects for medical devices
TC 211	Geographic information/Geomatics
TC 212	Clinical laboratory testing and in vitro diagnostic test systems
TC 213	Dimensional and geometrical product specifications and verification
TC 214	Elevating work platforms
TC 215	Health informatics
TC 216	Footwear
TC 217	Cosmetics
TC 218	Timber
TC 219	Floor coverings
TC 220	Cryogenic vessels
TC 221	Geosynthetics
TC 222	Personal financial planning
TC 223	Civil defense
TC 224	Service activities relating to drinking water supply systems and wastewater systems - Quality criteria of the service and performance indicators
TC 225	Market, opinion and social research - PROVISIONAL

EndNotes

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